APPENDIX A
Example of MARSSIM Applied to a Final Status Survey

A.1 Introduction

This appendix presents the final status survey for a relatively simple example of a radiation site. Portions of this example appear earlier in Chapter 5 and Chapter 8. This appendix highlights the major steps for implementing a final status survey and gathering information needed to prepare a report. The report's format will vary with the requirements of the responsible regulatory agency. The Final Status Survey Checklist given at the end of Section 5.5 serves as a general outline for this appendix—although not every point is discussed in detail. Chapters providing discussions on particular points are referenced at each step. This example presents detailed calculations for a single Class 1 survey unit. Section A.2 addresses the completion of steps 1-4 of the Data Quality Objectives (DQO) Process (see Appendix D, Sections D.1 to D.4). Section A.3 addresses the completion of steps 5-7 of the DQO Process (see Appendix D, Sections D.5 to D.7). Section A.4 covers survey performance. Section A.5 discusses evaluating the survey results using Data Quality Assessment (DQA, see Appendix E).

A.2 Survey Preparations

(Chapter 3- Historical Site Assessment)

The Specialty Source Manufacturing Company produced low-activity encapsulated sources of radioactive material for use in classroom educational projects, instrument calibration, and consumer products. The manufacturing process—conducted between 1978 and 1993—involved combining a liquid containing a known quantity of the radioactive material with a plastic binder. This mixture was poured into a metal form and allowed to solidify. After drying, the form and plastic were encapsulated in a metal holder which was pressure sealed. A variety of radionuclides were used in this operation, but the only one having a half-life greater than 60 days was ^{60}Co. Licensed activities were terminated as of April 1993 and stock materials containing residual radioactivity were disposed using authorized procedures. Decontamination activities included the initial identification and removal of contaminated equipment and facilities. The site was then surveyed to demonstrate that the radiological conditions satisfy regulatory agency criteria for release.

A.2.1 Identify the Radionuclides of Concern

(Section 4.3)

More than 15 half-lives have passed for the materials with a half-life of 60 days or less. Based on radioactive decay and the initial quantities of the radionuclides, the quantities that could remain at the site are negligible. A characterization survey confirmed that no radioactive contaminants, other than ^{60}Co, were present.

A.2.2 Determine Residual Radioactivity Limits (DCGLs)
(Section 4.3)

The objective of this survey is to demonstrate that residual contamination in excess of the release criterion is not present at the site. The $DCGL_W$ for ^{60}Co used for evaluating survey results is 8,300 Bq/m^2 (5,000 dpm/100 cm^2) for surface contamination of structures. The $DCGL_W$ for contamination in soil is 140 Bq/kg (3.8 pCi/g).[1]

A.2.3 Classify Areas Based on Contamination Potential.
(Section 4.4)

This facility consists of one administration/manufacturing building situated on approximately 0.4 hectares (1.0 acres) of land as shown in Figure A.1. The building is a concrete block structure on a poured concrete slab with a poured concrete ceiling. The northern portion of the building housed the manufacturing operations, and consists of a high-bay area of approximately 20 m x 20 m with a 7 m high ceiling. The remainder of the building is single-story with numerous small rooms partitioned by drywall construction. This portion of the building, used for administration activities, occupies an area of approximately 600 m^2 (20 m x 30 m). The license does not authorize use of radioactive materials in this area. Operating records and previous radiological surveys do not identify a potential for residual contamination in this section of the building. Figure A.2 is a drawing of the building.

The property is surrounded by a chain-link security fence. At the northern end of the property, the surface is paved and was used as a parking lot for employees and for truck access to the manufacturing and shipping/receiving areas. The remainder of the property is grass-covered. There are no indications of incidents or occurrences leading to radioactive material releases from the building. Previous surveys were reviewed and the results were determined to be appropriate for planning the final status survey. These surveys identified no radioactive contamination outside the building.

A.2.4 Identify Survey Units
(Section 4.6)

Based on the results of other decommissioning surveys at the site and the operating history, the following survey units were used to design the final status survey. All of the interior survey units consist of concrete surfaces (either poured concrete or cinder block) with the exception of the administration areas which are drywall. The results of previous surveys demonstrated that the same reference area could be used to represent the poured concrete and cinder block surfaces.

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[1] The DCGL values used in this appendix are meant to be illustrative examples and are not meant to be generally applied.

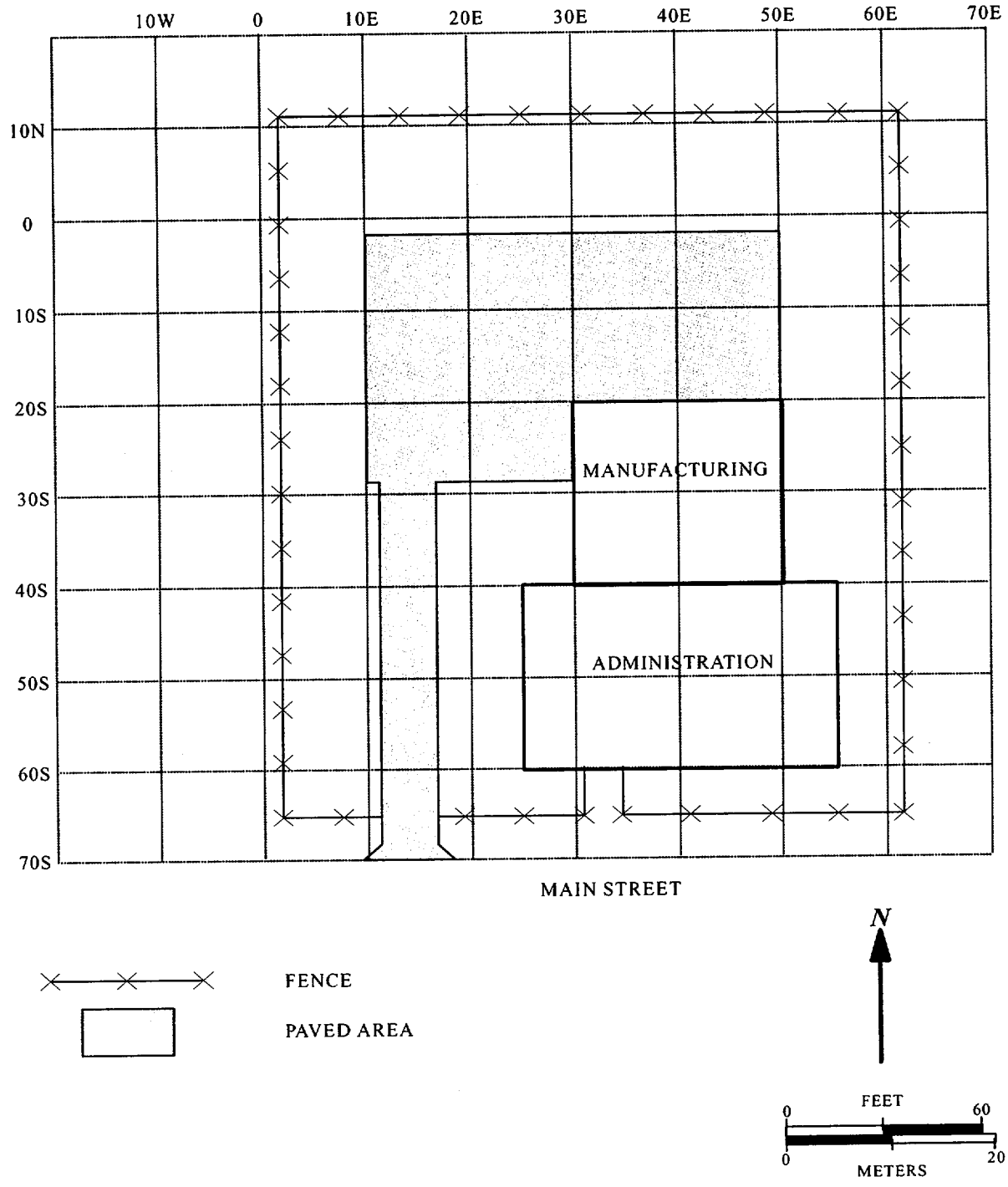


Figure A.1 Plot Plan of the Specialty Source Manufacturing Company

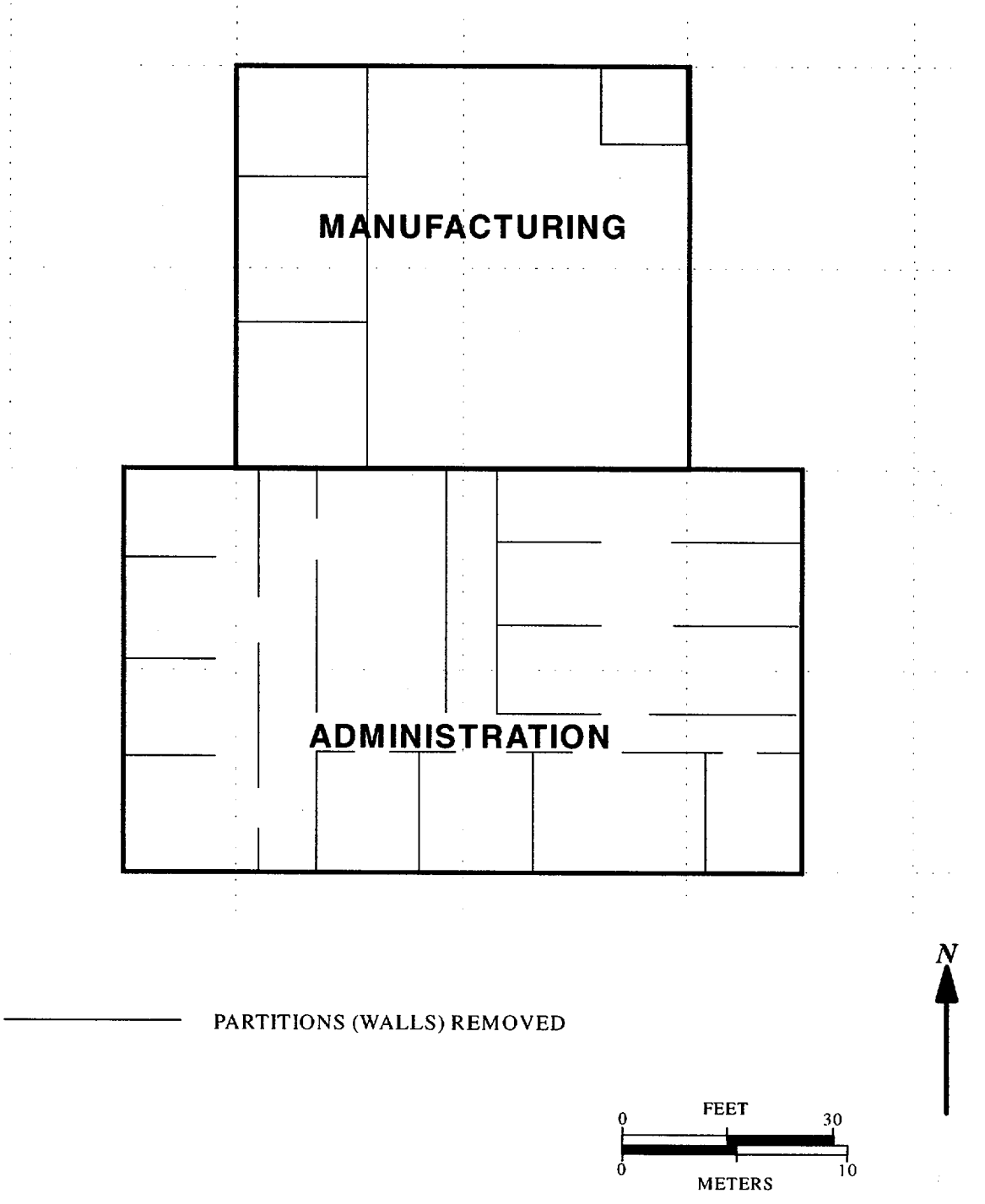


Figure A.2 Building Floor Plan

Structures

Class 1 — Floor and lower walls (up to 2 meters above the floor) of manufacturing area - 4 survey units of 140 m^2 each.

Class 2 — Upper walls (over 2 meters above the floor) of manufacturing area - 4 survey units of 100 m^2 each.
Ceiling of manufacturing area - 4 survey units of 100 m^2 each.
Paved area outside manufacturing area roll-up door - 1 survey unit of 60 m^2.

Class 3 — Floors and lower walls of administration areas - 1 survey unit.
Remainder of paved surfaces - 1 survey unit.

Land Areas

Class 3 — Lawn areas - 1 survey unit.

A.2.5 Select Survey Instrumentation and Survey Techniques

(Section 4.7, Chapter 6, Chapter 7, Appendix H, and Appendix M)

For interior surfaces, direct measurements of gross beta activity were made using one minute counts on a gas flow proportional counter with an MDC of 710 Bq/m^2 (425 dpm/100 cm^2). This is actually less than 10% of the DCGL for ^{60}Co. Surfaces were scanned using either a 573 cm^2 floor monitor with an MDC of 6,000 Bq/m^2 (3,600 dpm/100 cm^2) or a 126 cm^2 gas flow proportional counter with an MDC of 3,300 Bq/m^2 (2,000 dpm/100 cm^2).

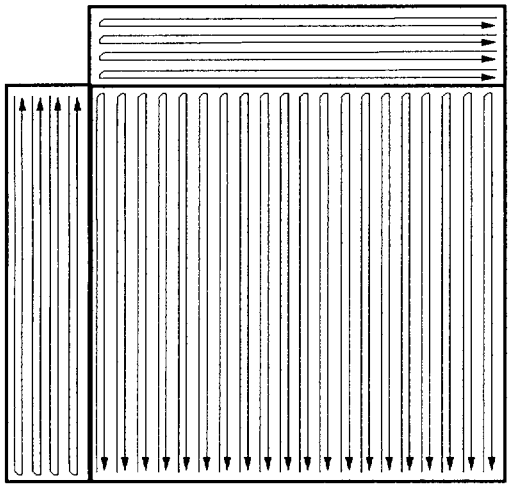
Exterior soil surfaces were sampled and counted in a laboratory using a Ge spectrometer with an MDC of 20 Bq/kg (0.5 pCi/g). This is actually slightly greater than 10% of the DCGL for ^{60}Co. Soil surfaces were scanned using a NaI(Tl) scintillator with an MDC of 185 Bq/kg (5.0 pCi/g) of ^{60}Co.

Examples of scanning patterns used in each of the Class 1, 2, and 3 areas are shown in Figure A.3.

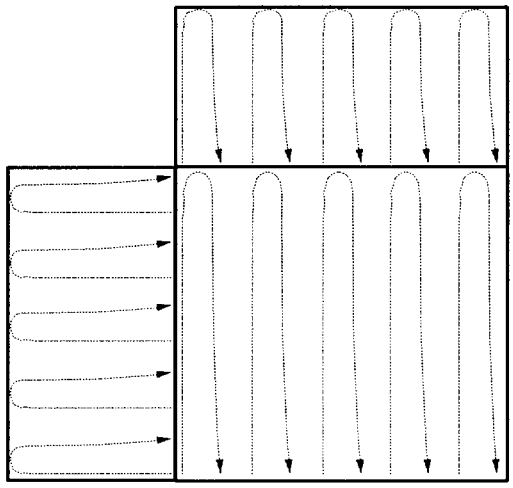
A.2.6 Select Representative Reference (Background) Areas

(Section 4.5)

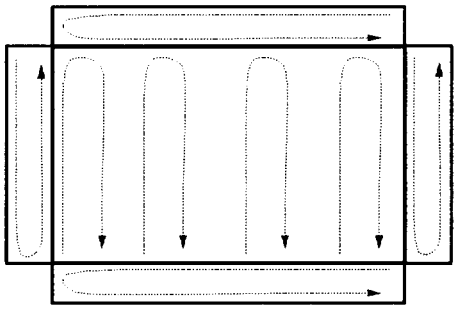
For the purposes of evaluating gross beta activity on structure surfaces, a building of similar construction was identified on the property immediately east of the site. This building served as a reference for surface activity measurements. Two reference areas—one for concrete surfaces and one for drywall surfaces—were required. Because ^{60}Co is not a constituent of background and evaluation of the soil concentrations was radionuclide-specific, a reference area was not needed for the land area surveys.



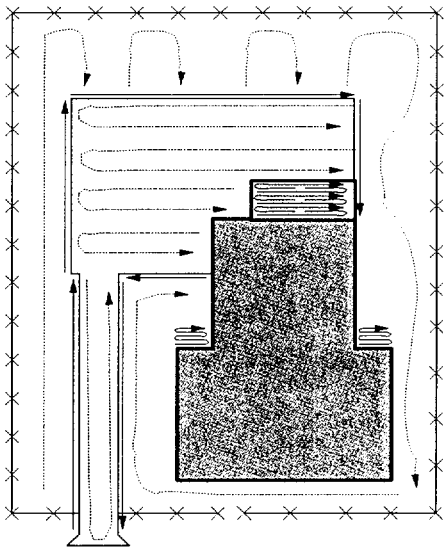
Interior Concrete Survey Units
Class 1 Floors - 100% Scan with Floor Monitor
Class 1 Walls - 100% Scans with Gas Flow
Proportional Counter



Manufacturing Area Upper Walls and Ceiling
Class 2 Areas - 25% Scans with Gas Flow
Proportional Counter



Administration/Office Areas
Class 3 Floors - 25% Scan with Floor Monitor
Class 3 Walls - 25% Scan with Gas Flow
Proportional Counter



Class 2 Paved Area - 100% Scan with Floor Monitor
Class 3 Paved Area - 25% Scan with NaI(Tl)
Class 3 Lawn Area - 100% Scan with NaI(Tl) at Downspouts
and Edge of Pavement (Runoff Areas)
10% Scan with NaI(Tl) on Remaining Lawn Area

Figure A.3 Examples of Scanning Patterns for Each Survey Unit Classification

A.2.7 Prepare Area
(Section 4.8)

Prior to the survey, and as part of the decommissioning process, all internal partitions were removed from the manufacturing area. Other items removed include the radioactive material control exhaust system, a liquid waste collection system, and other furnishings and fixtures not considered an integral part of the structure.

A.2.8 Establish Reference Coordinate Systems
(Section 4.8.5)

Land areas were gridded at 10 m intervals along north-south and east-west axes in preparation for the characterization survey as shown in Figure A.1. The grid was checked to verify its use for the final status survey.

Structure surfaces were already gridded at 2 m intervals, incorporating the floors and the lower 2 m of the walls. Figure A.4 is an example of the coordinate system installed for one of the Class 1 interior concrete survey units.

A.3 Survey Design

A.3.1 Quantify DQOs
(Section 2.3, Appendix D)

The null hypothesis for each survey unit is that the residual radioactivity concentrations exceed the release criterion (Scenario A, Figure D.5). Acceptable decision error probabilities for testing the hypothesis were determined to be α=0.05 and β=0.05 for the Class 1 interior concrete survey units, and α=0.025 and β=0.05 for all other survey units.

A.3.2 Construct the Desired Power Curve
(Section 2.3, Appendix D.6, Appendix I.9)

The desired power curve for the Class 1 interior concrete survey units is shown in Figure A.5. The gray region extends from 4,200 to 8,300 Bq/m^2 (2,500 to 5,000 dpm/100 cm^2). The survey was designed for the statistical test to have 95% power to decide that a survey unit containing less than 4,200 Bq/m^2 (2,500 dpm/100 cm^2) above background meets the release criterion. For the same test, a survey unit containing over 17,000 Bq/m^2 (10,000 dpm/100 cm^2) above background had less than a 2.5% probability of being released.

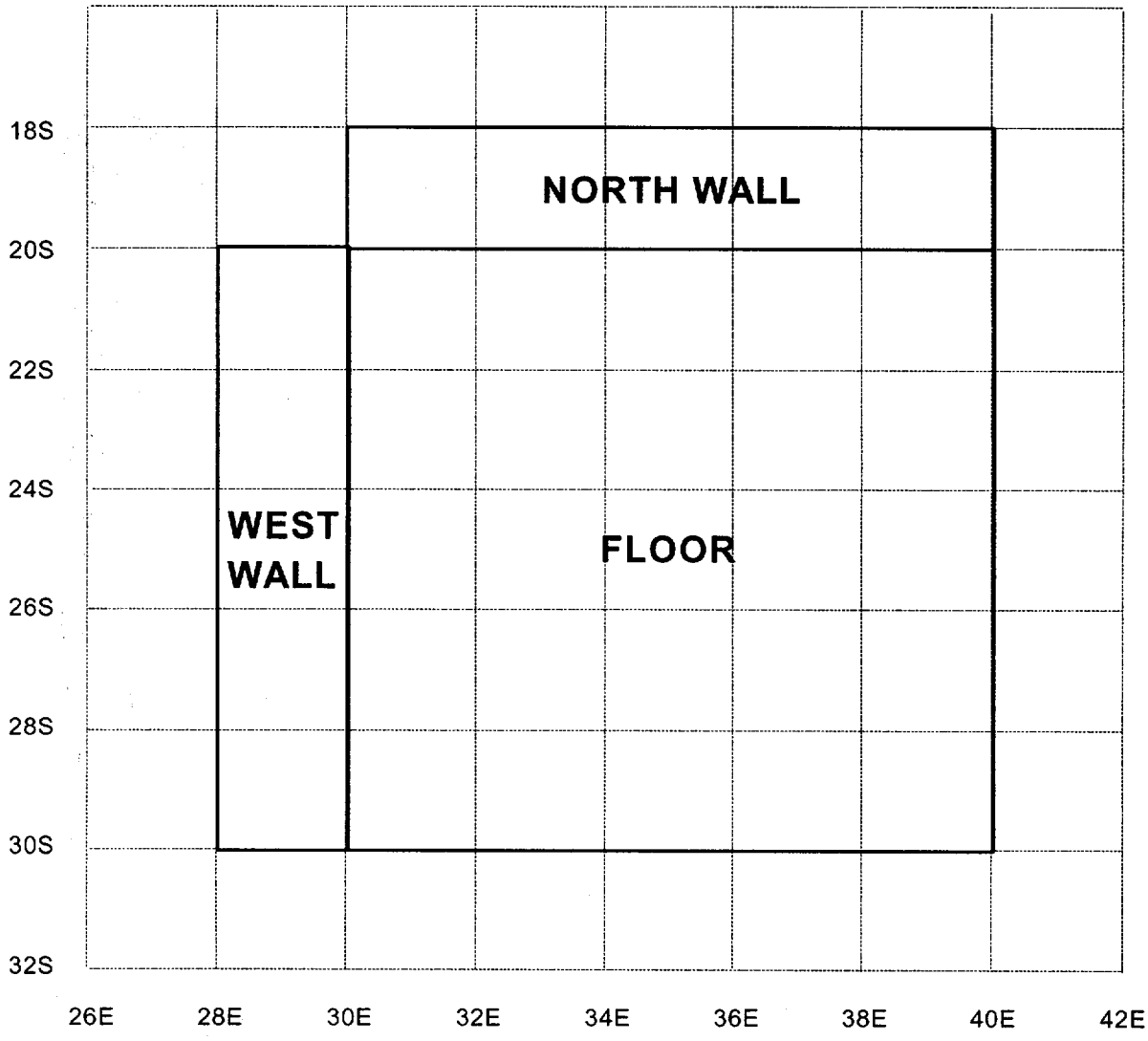


Figure A.4 Reference Coordinate System for the Class 1 Interior Concrete Survey Unit

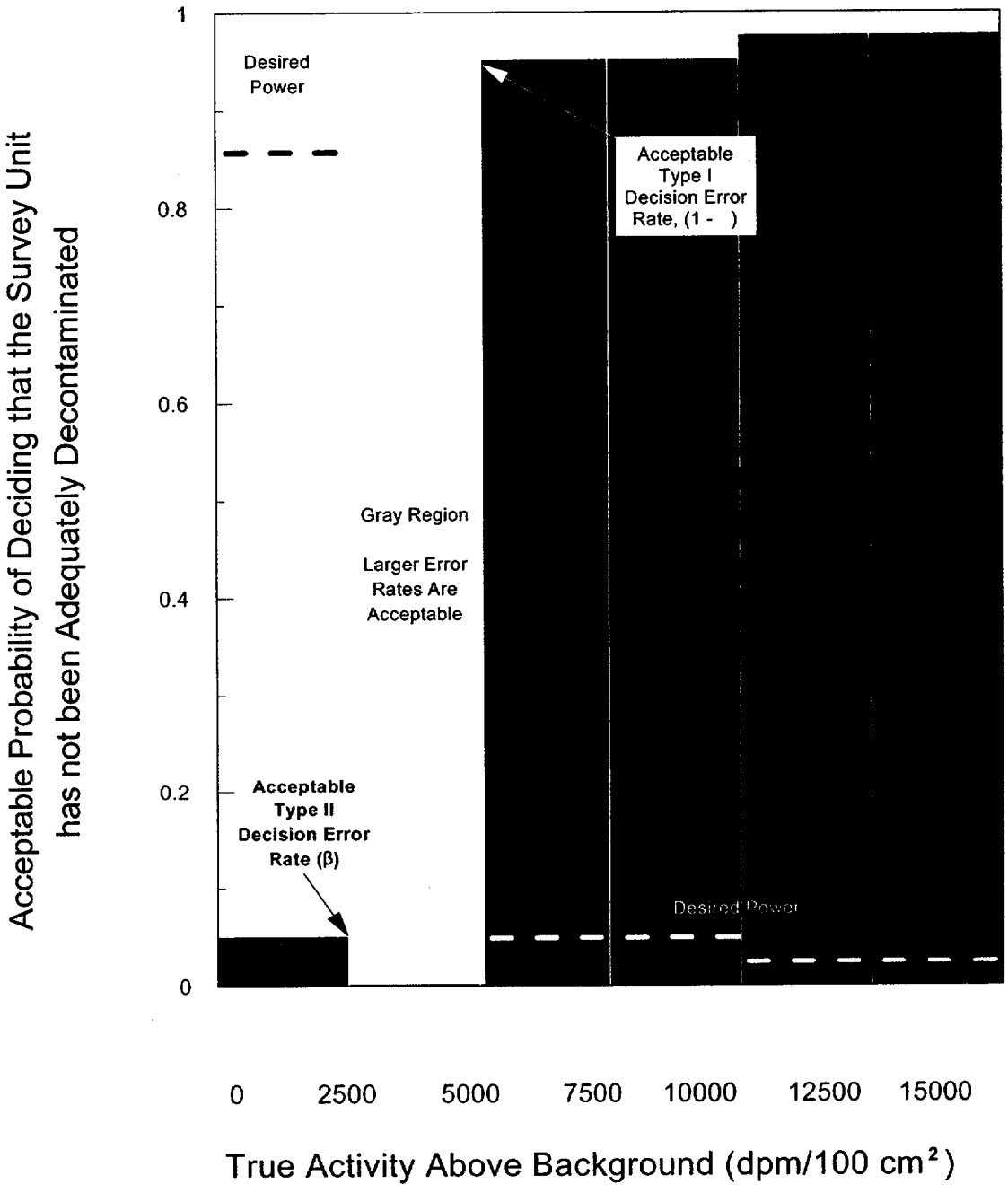


Figure A.5 Power Chart for the Class 1 Interior Concrete Survey Unit

A.3.3 Specify Sample Collection and Analysis Procedures
(Chapter 7)

In the Class 3 exterior survey unit soil cores were taken to a depth of 7.5 cm (3 in.) based on development of DQOs, the conceptual site model, and the assumptions used to develop the DCGLs. Each sample was labeled with the location code, date and time of sampling, sealed in a plastic bag, and weighed prior to shipment to the analytical laboratory. At the laboratory, the samples were weighed, dried, and weighed again. The samples were ground to a uniform particle size to homogenize the samples consistent with the modeling assumptions used to develop the DCGLs. One hundred gram (100 g) aliquots were gamma counted using a germanium detector with multichannel analyzer.

The decision to use radionuclide-specific measurements for soil means that the survey of the Class 3 exterior soil surface survey unit was designed for use with the one-sample Sign test.

A.3.4 Provide Information on Survey Instrumentation and Techniques
(Chapter 6)

A gas flow proportional counter with 20 cm^2 probe area and 16% 4π response was placed on the surface at each direct measurement location, and a one minute count taken. Calibration and background were checked before and after each series of measurements. The $DCGL_W$, adjusted for the detector size and efficiency, is:

$$(5{,}000 \text{ dpm}/100 \text{ cm}^2)\ (0.20)\ (0.16) = 160 \text{ cpm} \qquad \text{A-1}$$

The decision to use total activity measurements for interior surfaces means that the survey of all the interior survey units was designed for use with the two-sample WRS test for comparison with an appropriate reference area.

A.3.5 Determine Numbers of Data Points
(Section 5.5.2.2)

This facility contains 15 survey units consisting of interior concrete surfaces, interior drywall surfaces, exterior surface soil, and exterior paved surfaces.

Concrete Surfaces

The site has 12 interior concrete survey units to be compared with 1 reference area. The same type of instrument and method were used to perform measurements in each area.

The lower bound of the gray region is selected to be one-half the DCGL, and Type I and Type II error values (α and β) of 0.05 were selected. The number of samples/measurements to be obtained, based on the requirements of the statistical tests, was determined using Equation 5-1 in Section 5.5.2.2:

$$N = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{3(P_r - 0.5)^2} \qquad \text{A-2}$$

From Table 5.2 it is found that $Z_{1-\alpha} = Z_{1-\beta} = 1.645$ for $\alpha = \beta = 0.05$.

The parameter P_r depends on the relative shift, Δ/σ. The width of the gray region, Δ, in Figure A.5 is 4,200 Bq/m^2 (2,500 dpm/100 cm^2), which corresponds to 80 cpm. Data from previous scoping and characterization surveys indicate that the background level is 45 ± 7 (1σ) cpm. The standard deviation of the contaminant in the survey unit (σ_s) is estimated at ± 20 cpm. When the estimated standard deviation in the reference area and the survey units are different, the larger value should be used to calculate the relative shift. Thus, the value of the relative shift, Δ/σ, is (160-80)/20 or 4.[2] From Table 5.1, the value of P_r is approximately 1.000.

The number of data points for the WRS test of each combination of reference area and survey units according to the allocation formula was:

$$N = \frac{(1.645+1.645)^2}{3(1.000-0.5)^2} = 14.4 \qquad \text{A-3}$$

Adding an additional 20% and rounding up yielded 18 data points total for the reference area and each survey unit combined. Note that the same result is obtained by simply using Table 5.3 or Table I.2b with $\alpha = \beta = 0.05$ and $\Delta/\sigma = 4$. Of this total number, 9 were planned from the reference area and 9 from each survey unit. The total number of measurements calculated based on the statistical tests was 9 + (12)(9) = 117.

A.3.6 Evaluate the power of the statistical tests against the DQOs.
(Appendix I.9.2)

Using Equation I-8, the prospective power expected of the WRS test was calculated using the fact that 9 samples were planned in each of the survey units and the reference area. The value of σ_s was taken to be 20 cpm, the larger of the two values anticipated for the reference area (7 cpm) and the survey unit (20 cpm). This prospective power curve is shown in Figure A.6.

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[2] Ordinarily Δ/σ would be adjusted to a value between 1 and 3. For this example the adjustment was not made.

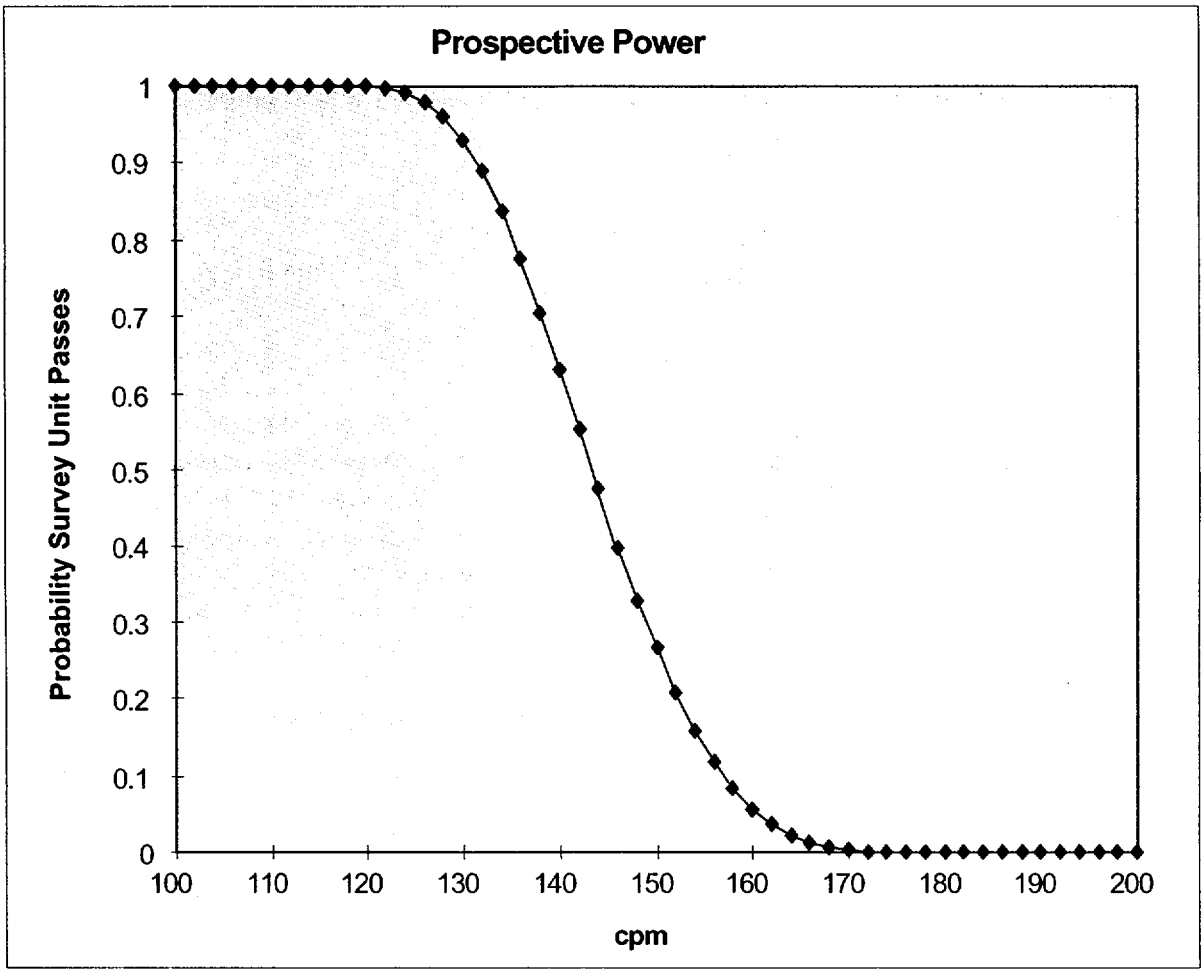

Figure A.6 Prospective Power Curve for the Class 1 Interior Concrete Survey Unit

A.3.7 Ensure that the Sample Size is Sufficient for Detecting Areas of Elevated Activity (Chapter 5.5.2.4)

The Class 1 concrete interior survey units each have an area of 140 m^2 (Figure A.7). The distance between measurement locations in these survey units was:

$$L = \sqrt{\frac{A}{0.866n}} = \sqrt{\frac{140}{0.866\ (10)}} = 4.2\ m \qquad \text{A-4}$$

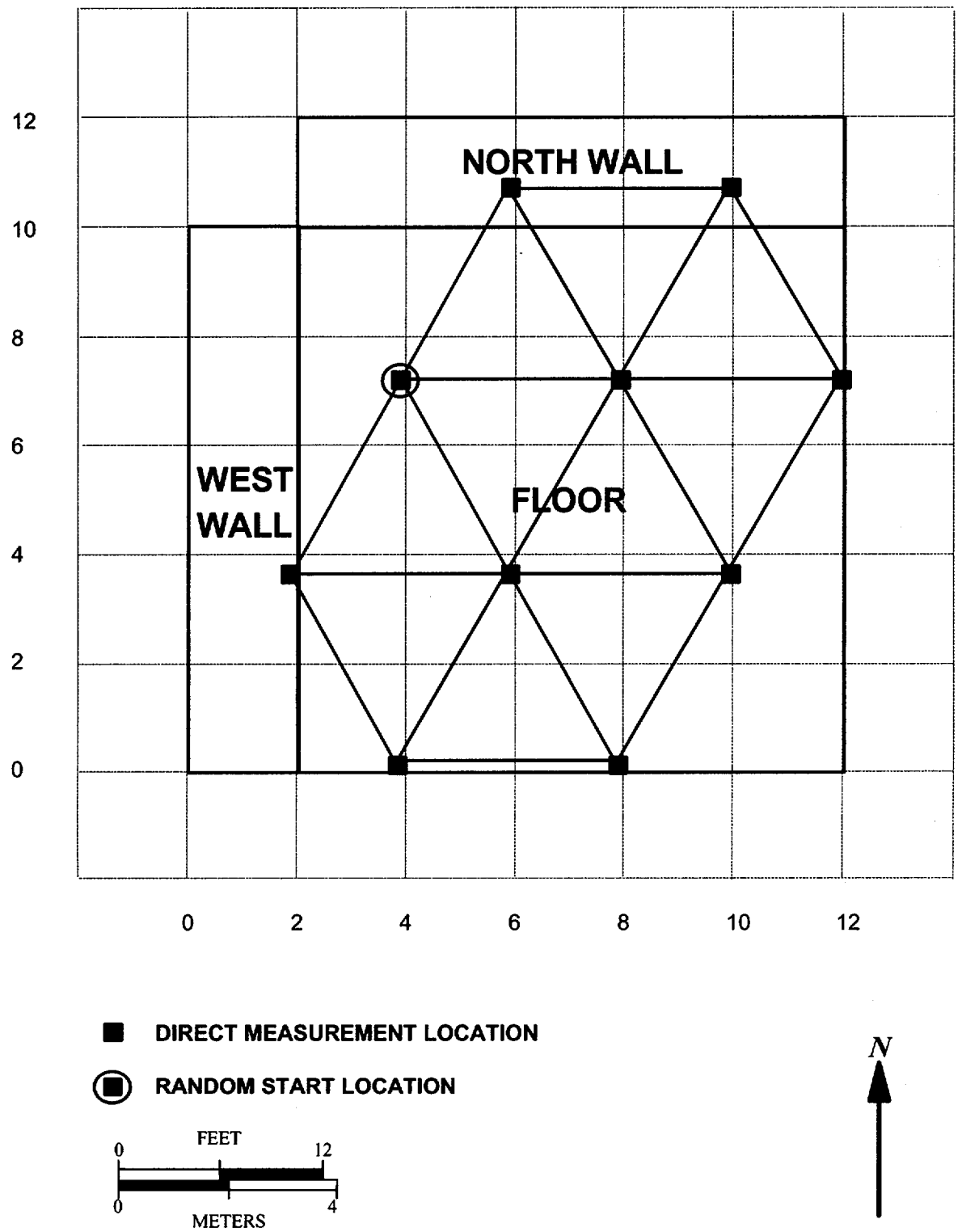

Figure A.7 Measurement Grid for the Class 1 Interior Concrete Survey Unit

The result for L was rounded *down* to the nearest meter, giving L = 4 m. This resulted in an area between sampling points of $0.866L^2 = 13.9$ m^2. The $DCGL_W$ of 8,300 Bq/m^2 (5,000 dpm/100 cm^2) was well above the scanning MDC of 6,000 Bq/m^2 (3,600 dpm/100 m^2) for the least sensitive of the two scanning instruments (the floor monitor). Therefore, no adjustment to the number of data points to account for areas of elevated activity was necessary.

A.3.8 Specify Sampling Locations
(Chapter 5.5.2.5)

Two random numbers between zero and one were generated to locate the random start for the sampling grid. Using Table I.6 in Appendix I, 0.322467 and 0.601951 were selected. The random start for triangular sampling pattern was found by multiplying these numbers by the length of the reference grid X and Y axes:

$$X = 0.322467 \times 12 \text{ m} = 3.9 \quad \text{A-5}$$
$$Y = 0.601951 \times 12 \text{ m} = 7.2 \quad \text{A-6}$$

The first row of measurement locations was laid out at 4m intervals parallel to one axis of the reference grid. The second row was positioned (0.866)(4) = 3.5 m from the first row, with measurement locations offset by 2 m from those in the first row. The measurement grid is shown in Figure A.7. When the measurement grid was constructed it was found that 10 measurement locations were identified within the boundaries of the survey unit, which is greater than the 9 measurement locations calculated to be required for the statistical test. Because the spacing between the measurements (L) is important for identifying areas of elevated activity, *all* of the identified sampling locations should be used.

A.3.9 Develop Quality Control Procedures
(Section 4.9)

A.3.10 Document Results of Planning into a Quality Assurance Project Plan
(Section 9.2)

A.4 Conducting Surveys

A.4.1 Perform Reference (Background) Area Measurements and Scanning
(Chapter 6)

A.4.2 Collect and Analyze Samples
(Chapter 7)

A.5 Evaluating Survey Results

A.5.1 Perform Data Quality Assessment
(Chapter 8.2)

The data from the one Class 1 interior concrete survey unit and its associated reference area are given in Table A.1. Since ten sampling locations were identified, ten results are listed for the survey unit.[3] The average measurement in the survey unit is 206 cpm, and in the reference area the average is 46 cpm. The means and the medians are nearly equal in both cases. The standard deviations are also consistent with those estimated during the survey design. The survey unit clearly contains residual radioactivity close to the $DCGL_W$ of 160 cpm (calculated using Equation A-1).

Table A.1 Class 1 Interior Concrete Survey Unit and Reference Area Data

	Reference Area (cpm)	Survey Unit (cpm)
	45	205
	36	207
	32	203
	57	196
	46	211
	60	208
	39	172
	45	216
	53	233
	42	209
mean	46	206
standard deviation	9	15.4
median	45	207.5

[3]There are also ten results listed for the reference area. This is only because there were also ten locations identified there when the grid was laid out. Had nine locations been found, the survey would proceed using those nine locations. There is no requirement that the number of sampling locations in the survey unit and reference area be equal. It is only necessary that at least the minimum number of samples required for the statistical tests is obtained in each.

The stem and leaf displays (see Appendix I.7) for the data appear in Table A.2. They indicate that the data distributions are unimodal with no notable asymmetry. There are two noticeably extreme values in the survey unit data set, at 172 and 233 cpm. These are both about 2 standard deviations from the mean. A check of the data logs indicated nothing unusual about these points, so there was no reason to conclude that these values were due to anything other than random measurement variability.

Table A.2 Stem and Leaf Displays for Class 1 Interior Concrete Survey Unit

Reference Area				
30	6	2	9	
40	5	5	6	2
50	7	3		
60	0			

Survey Unit					
170	2				
180					
190	6				
200	5	7	3	8	9
210	1	6			
220					
230	3				

A Quantile-Quantile plot (see Appendix I.8) of this data, shown in Figure A.8, is consistent with these conclusions. The median and spread of the survey unit data are clearly above those in the reference area. The middle part of the curve has no sharp rises. However, the lower and upper portion of the curve both show a steep rise due to the two extreme measurements in the survey unit data set.

A.5.2 Conduct Elevated Measurement Comparison
(Section 8.5.1)

The $DCGL_W$ is 160 cpm above background. Based on an area between measurement locations 13.9 m^2 for L = 4 m, the area factor (from Table 5.7) is approximately 1.5. This means the $DCGL_{EMC}$ is 240 cpm above background. Even without subtracting the average background value of 46, there were no survey unit measurements exceeding this value. All of the survey unit measurements exceed the $DCGL_W$ and six exceed 206 cpm—the $DCGL_W$ plus the average background. If any of these data exceeded three standard deviations of the survey unit mean, they might have been considered unusual, but this was not the case. Thus, while the amount of residual radioactivity appeared to be near the release criterion, there was no evidence of smaller areas of elevated residual radioactivity.

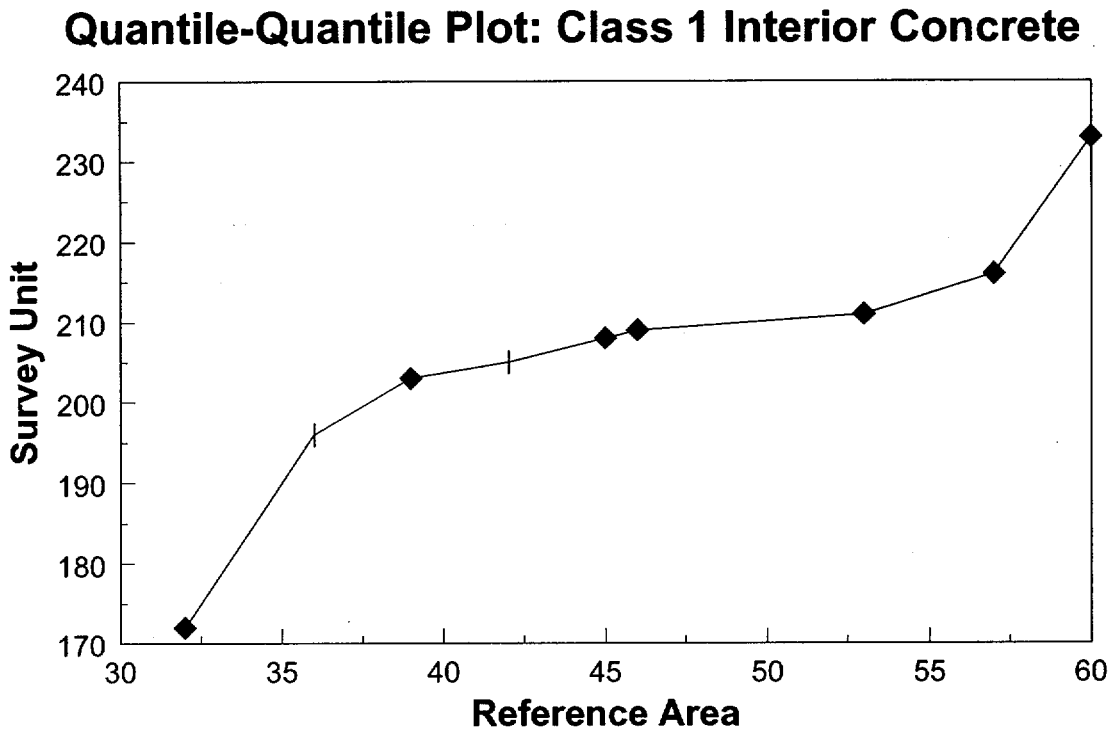

Figure A.8 Quantile-Quantile Plot for the Class 1 Interior Concrete Survey Unit

A.5.3 Conduct Statistical Tests
(Section 8.3, 8.4)

For the Class 1 interior concrete survey unit, the two-sample nonparametric statistical tests of Section 8.4 were appropriate since, although the radionuclide of concern does not appear in background, radionuclide specific measurements were not made. This survey unit was classified as Class 1, so the 10 measurements performed in the reference area and the 10 measurements performed in the survey unit were made on random start triangular grids.

Table A.3 shows the results of the twenty measurements in the first column. The average and standard deviation of the reference area measurements were 46 and 9, respectively. The average and standard deviation of the survey unit measurements were 206 and 15, respectively.

Table A.3 WRS Test for Class 1 Interior Concrete Survey Unit

Data	Area	Adjusted Data	Ranks	Reference Area Ranks
45	R	205	7.5	7.5
36	R	196	4	4
32	R	192	3	3
57	R	217	15	15
46	R	206	9	9
60	R	220	16	16
39	R	199	5	5
45	R	205	7.5	7.5
53	R	213	13	13
42	R	202	6	6
211	S	211	12	0
208	S	208	10	0
172	S	172	1	0
216	S	216	14	0
233	S	233	18	0
209	S	209	11	0
237	S	237	19	0
176	S	176	2	0
253	S	253	20	0
229	S	229	17	0
Sum=			210	86

The analysis proceeded as described in Section 8.6.3. In the "Area" column, the code "R" is inserted to denote a reference area measurement, and "S" to denote a survey unit measurement. In the "Data" column, the data were simply listed as obtained. The Adjusted Data were obtained by adding the $DCGL_W$ to the reference area measurements and leaving the survey unit measurements unchanged. The ranks of the Adjusted Data appear in the "Ranks" column. They range from 1 to 20, since there is a total of 20 (10+10) measurements. The sum of *all* of the ranks is 20(20+1)/2 = 210. It is recommended to check this value as a guard against errors in the rankings.

The "Reference Area Ranks" column contains only the ranks belonging to the reference area measurements. The total is 86. This was compared with the entry in Table I.4 for $\alpha = 0.05$, with $n = 10$ and $m = 10$. This critical value is 127. Thus, the sum of the reference area ranks was *less* than the critical value and the null hypothesis—that the survey unit concentrations exceed the $DCGL_W$—was accepted.

Again, as in Section 8.6.3, the retrospective power curve for the WRS test was constructed as described in Appendix I.9, using Equations I-8, I-9, and I-10, together with the actual number of concentration measurements obtained, N. The power as a function of Δ/s was calculated using the observed standard deviation, s = 15.4, in place of σ. The values of Δ/σ were converted to cpm using:

$$\text{cpm} = \text{DCGL}_W - (\Delta/\sigma)(\text{observed standard deviation}) \qquad \text{A-7}$$

The results for this example are plotted in Figure A.9, showing the probability that the survey unit would have passed the release criterion using the WRS test versus cpm of residual radioactivity. This curve shows that the data quality objectives were easily met. The curve shows that a survey unit with less than about 130 cpm above background would almost always pass and that a survey unit with more than about 170 cpm above background would almost always fail.

A.5.4 Estimate Amount of Residual Radioactivity
(Chapter 8.5.2.1)

The amount of residual radioactivity in the survey unit above background was estimated following the WRS test using the difference between the mean measurement in the survey unit and the mean measurement in the reference area: $\delta = 206 - 46 = 160$. This was converted to a surface area activity concentration of 8,300 Bq/m^2 (5,000 dpm/100 cm^2), which is just at the limiting value, DCGL_W.

The difference in the median measurements (207.5 - 45 = 162.5) was converted to a surface activity concentration of 8,500 Bq/m^2 (5,100 dpm/100 cm^2). This slightly exceeds the DCGL_W.

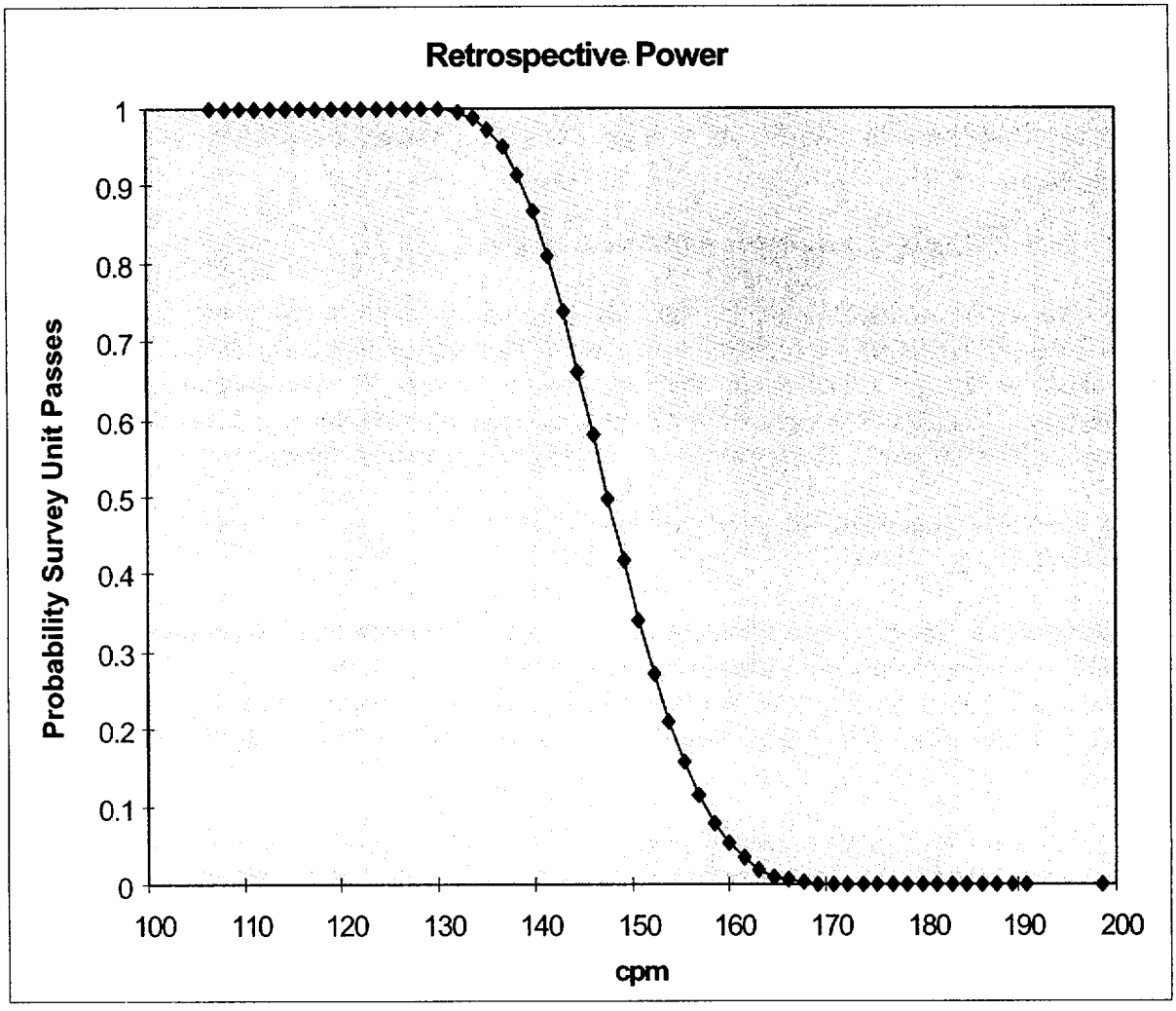

Figure A.9 Retrospective Power Curve for the Class 1 Interior Concrete Survey Unit

APPENDIX B

SIMPLIFIED PROCEDURE FOR CERTAIN USERS OF SEALED SOURCES, SHORT HALF-LIFE MATERIALS, AND SMALL QUANTITIES

A large number of users of radioactive materials may use a simplified procedure to demonstrate regulatory compliance for decommissioning, avoiding complex final status surveys. Sites that qualify for simplified decommissioning procedures are those where radioactive materials have been used or stored only in the form of: non-leaking, sealed sources; short half-life radioactive materials (*e.g.*, $t_{1/2} \leq 120$ days) that have since decayed to insignificant quantities; small quantities exempted or not requiring a specific license from a regulatory authority; or combinations of the above.

The user of a site that may qualify for implementation of a simplified procedure should provide the regulatory authority with a minimum of: (1) a certification that no residual radioactive contamination attributable to the user's activities is detectable by generally accepted survey methods for decommissioning; and (2) documentation on the disposal of nuclear materials, such as the information required in Form NRC-314 (Certification of Disposition of Materials). This minimum information may be used by the regulatory authority to document protection of both the public health and safety and the environment, based on the transfer, decay, or disposal of radioactive material in some authorized manner.

Normally, the absence of radioactive contamination can be demonstrated by: (1) documenting the amounts, kinds and uses of radionuclides as well as the processes involved; (2) conducting a radiation survey of the site; and (3) submitting a report on this survey. More specifically, a user of a qualified site should document from process knowledge and the nature of the use that either no or unmeasurable quantities of radioactive material remain onsite—whether on surfaces, buried, imbedded, submersed, or dissolved. The submittal to the regulatory authority should include possession history, use of the radioactive materials, and, if applicable, results of all leak tests. Where only small quantities or short half-life materials were handled, the regulatory authority may consider the documentation on a case-by-case basis.

For those sites where a simple final status survey is conducted to demonstrate compliance with the release criterion, the following information should be included in the final status survey report:

- basis for selecting the instrumentation used for the survey
- nature of the radionuclides surveyed
- measurement techniques and instruments used, including references for procedures and protocols used to perform the measurements

- minimum detectable concentrations (MDCs) of the instruments and measurement systems used to perform the measurements
- calibration, field testing, and maintenance of the instrumentation
- qualifications of the personnel using the instrumentation
- methods used to interpret the survey measurements
- qualifications of the personnel interpreting the survey measurements
- measurement results and measurement locations including the operator's name, instrument model and serial number, date the measurement was performed, and traceability of the measurement location

The number of measurements in each survey unit and each reference area can be determined using Table 5.3 for sites where the radionuclide of potential interest is present in background. The number of measurements for each survey unit where the radionuclide is not present in background can be determined using Table 5.5. Values for acceptable decision error levels (α and β) and the relative shift (Δ/σ) can be determined as described in Section 5.5.2. For sites where the simplified approach in this appendix is appropriate, reasonably conservative values for these parameters would be $\alpha = 0.05$, $\beta = 0.05$, and $\Delta/\sigma = 1$. After increasing the number of measurements by 20% to ensure adequate power for the statistical tests, Table 5.3 and Table 5.5 list a value of approximately 30 measurements for each survey unit and each reference. Therefore, 30 measurements may be used in place of the guidance in Section 5.5.2 at sites that qualify for the simplified survey design process.

The results of the survey should be compared to derived concentration guideline levels (DCGLs) using an appropriate statistical test, such as the Student's *t* test or Wilcoxon test. If all measurements are less than the $DCGL_W$, then the statistics do not need to be addressed because the conclusions are obvious. If the mean of the measurements exceeds the $DCGL_W$, the survey unit obviously fails to demonstrate compliance and the statistics do not need to be addressed.

Radiation levels and concentrations should be reported as follows:

- For external dose rates, units of:
  - milli-Sieverts (micro-rem) per hour at one meter from surfaces;

- For levels of radioactive materials, including alpha and beta measurements, units of:
  - Bq/m^2 (dpm/100 cm^2, pCi/100 cm^2) (removable and fixed) for surfaces;
  - Bq/L (pCi/mL) for water;
  - Bq/kg (pCi/g) for solids such as soils or concrete.

APPENDIX C
REGULATIONS AND REQUIREMENTS ASSOCIATED WITH RADIATION SURVEYS AND SITE INVESTIGATIONS[1]

C.1 EPA Statutory Authorities

The U.S. Environmental Protection Agency administers several statutes that address various aspects of the cleanup of radioactively contaminated sites. Listed below are the statutes, the implementing regulations, and the responsible EPA offices.

C.1.1 The Office of Air and Radiation (OAR) administers several statutes and implementing regulations:

- Clean Air Act (CAA) as amended (42 U.S.C. 7401-7671 q.): The CAA protects and enhances the nation's air quality through national ambient air quality standards, new source performance standards, and other provisions. Radionuclides are a hazardous air pollutant regulated under Section 112 of the Act.

  - National Emissions Standard for Hazardous Air Pollutants for Radionuclides (40 CFR Part 61, 10 CFR 20.101-20.108)

- Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978 (42 U.S.C. 2022): UMTRCA requires stabilization and control of byproduct materials (primarily mill tailings) at licensed commercial uranium and thorium processing sites. NRC and DOE implement standards under this Act.

  - Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings (40 CFR Part 192)

    This regulation, along with "Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material From Ores Processed Primarily for Their Source Material Content" (10 CFR 40, Appendix A), issued by the NRC and EPA, establish technical criteria related to the operation, decontamination, decommissioning, and reclamation of uranium or thorium mills and mill tailings. Both regulations provide design requirements for closure of the mill's waste disposal area.

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[1] The user of this manual should consult the text of the statutes and regulations listed in this Appendix to ensure compliance with all requirements applicable to a specific site and to ensure the use of current versions of applicable statutes and regulations.

The principal radiological hazards from uranium milling operations and mill tailings disposal are due to radon gas emissions originating from uranium and thorium daughters. Release rates to the atmosphere are limited to an average rate of 0.7 Bq (20 pCi) per square meter per second. This rate is applicable to any portion of a licensed or disposal site unless land areas do not contain radium concentrations—averaged over 100 square meters—greater than (i) 185 Bq/kg (5 pCi/g) of radium averaged over the first 15 centimeters below the surface and (ii) 555 Bq/kg (15 pCi/g) of radium averaged over 15 cm thick layers more than 15 centimeters below the surface.

- Atomic Energy Act (AEA) as amended (42 U.S.C. 2011-2296): The AEA requires the management, processing, and utilization of radioactive materials in a manner that protects public health and the environment. This is the principal basis for EPA, NRC and DOE authorities.

  The AEA requires that source, special nuclear, and byproduct materials be managed, processed, and used in a manner that protects public health and the environment. Under the AEA and Reorganization Plan No. 3 of 1970, EPA is authorized to issue federal guidance on radiation protection matters as deemed necessary by the Agency or as mandated by Congress. This guidance may be issued as regulations, given that EPA possesses the authority to promulgate generally applicable radiation protection standards under Reorganization Plan No. 3. For example, under AEA authority EPA promulgated its environmental radiation protection standards for nuclear power operations in 40 CFR Part 190.

  In conjunction with the AEA, EPA presently supports the following:

  – Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear, High-Level and Transuranic Radioactive Wastes (40 CFR 191)

- Nuclear Waste Policy Act (NWPA), as amended (Pub. L. 100-507, 42 U.S.C. 10101): The NWPA is intended to provide an orderly scheme for the selection and development of repositories for high-level radioactive waste and spent nuclear fuel.

- Low Level Radioactive Waste Policy Act (LLRWPA), as amended (Pub. L. 99-240, 42 U.S.C. 2021b): LLRWPA assigns States responsibility for ensuring adequate disposal capacity for low-level radioactive waste generated within their borders.

- Indoor Radon Abatement Act of 1988 (15 U.S.C. 2601 Sec. 301-311)

C.1.2 The Office of Emergency and Remedial Response (OERR) administers the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, as amended (Pub. L. 99-499, 42 U.S.C. 9601-9657)

- CERCLA authorizes EPA, consistent with the National Oil and Hazardous Substances Contingency Plan (NCP, 40 CFR 300) to provide for remedial action in response to releases or substantial threats of releases of hazardous substances into the environment. Hazardous substances are defined as any substance designated or listed under the Clean Air Act, the Federal Water Pollution Control Act, the Toxic Substances Control Act, and the Resource Conservation and Recovery Act. Because the CAA designated radionuclides as a hazardous air pollutant, the provisions of CERCLA apply to radionuclides.

C.1.3 The Office of Solid Waste (OSW) administers the Resource Conservation and Recovery Act of 1976 (RCRA), as amended (Pub. L. 94-580, 42 U.S.C. 6901 *et seq.*)

- RCRA provides for detailed regulation of hazardous waste from generation to final disposal. Hazardous waste generators and transporters must comply with EPA standards. Owners and operators of treatment, storage, or disposal facilities must obtain RCRA permits. Materials defined in the AEA are expressly excluded from the definition of solid waste, and, thus from regulation under RCRA. Naturally occurring and accelerator produced radioactive materials, however, are not excluded.

C.1.4 The Office of Water (OW) administers several statutes and implementing regulations:

- Section 14.2 of the Public Health Service Act as amended by the Safe Drinking Water Act (SDWA) as amended (Pub. L. 93-523, 42 U.S.C. 300f *et seq.*). As amended in 1986, SDWA seeks to protect public water supply systems through protection of groundwater. Any radioactive substance that may be found in water is regulated under the Act (although the current regulations only specify a limited number of individual substances).
  - Maximum Contaminant Levels (includes certain radionuclides). (40 CFR 141.11-141.16)
- Clean Water Act as amended (Pub. L. 92-500, 33 U.S.C. 1251 *et seq.*)
  - Requirements (40 CFR Parts 131, 400-469) established pursuant to sections 301, 302, 303 (including State water quality standards), 306, 307, (including Federal Pretreatment requirements for discharge into a publicly owned treatment works), and 403 of the Clean Water Act.

C.1.5 The Office of Prevention, Pesticides and Toxic Substances administers the Toxic Substances and Control Act (TSCA; 15 U.S.C. 2601)

- TSCA regulates the manufacture, distribution in commerce, processing, use, and disposal of chemical substances and mixtures. Materials defined in the AEA are expressly excluded from TSCA. However, naturally occurring and accelerator produced radionuclides are not excluded.

C.2 DOE Regulations and Requirements

C.2.1 Authorities of the Department of Energy

The Department of Energy Organization Act, which created DOE, the Energy Reorganization Act of 1974, which created the Energy Research and Development Administration, and the Atomic Energy Act of 1954[2] provide the basic authorities of the Department of Energy. The principal DOE statutory authorities and regulations that pertain to radiation protection are shown in Table C.1.

C.2.1.1 Atomic Energy Act of 1954, as amended

The Atomic Energy Act of 1954 established a program of private ownership and use of nuclear materials and nuclear facilities, such as nuclear research reactors, and a program for government regulation of those applications. (Prior to 1954, all source, byproduct, and special nuclear materials were government owned). The Atomic Energy Commission was given both the regulatory authorities and the mission to develop both the peaceful and military uses of atomic energy. The Act also retained the Atomic Energy Commission as the civilian agency responsible for weapons programs production, development and research consistent with the Atomic Energy Act of 1946.

Under the Act, the Atomic Energy Commission was responsible for establishing regulations ensuring the safety of commercial facilities and establishing requirements that ensure public protection from radiation and radioactive materials resulting from or used in its research, development, and production activities.

[2]The Atomic Energy Commission was created by the Atomic Energy Act of 1946, not the 1954 act.

Table C.1

DOE AUTHORITIES, ORDERS AND REGULATIONS RELATED TO RADIATION PROTECTION

Statutes

Atomic Energy Act of 1954, as amended

Energy Reorganization Act of 1974

Uranium Mill Tailings Radiation Control Act of 1978, as amended

Nuclear Non-Proliferation Act of 1978

Department of Energy Organization Act of 1980

West Valley Demonstration Project Act of 1980

Nuclear Waste Policy Act of 1982

Low-Level Waste Policy Act of 1980

Low-Level Waste Policy Amendments Act of 1985

Energy Policy Act of 1992

Waste Isolation Pilot Plant Land Withdrawal Act

Price Anderson Act

DOE Regulations

10 CFR Part 835, "Occupational Radiation Protection"

Executive Orders

Executive Order 12580

DOE Orders

Order 5400.1, "General Environmental Protection Program"
Order 5400.2A, "Environmental Compliance Issue Coordination"
Order DOE 5400.5, "Radiation Protection of the Public and the Environment"
Order DOE 5400.4, "Comprehensive Environmental, Response, Compensation and Liability Act Requirements"
Order DOE 5440.1E, "National Environmental Policy Act Compliance Program"
Order DOE 5480.1B, "Environment, Safety and Health Program for Department of Energy Facilities"
Order DOE 5480.3, "Safety Requirements for the Packaging and Transportation of Hazardous Materials, Hazardous Substances & Hazardous Wastes"
Order DOE 5480.4, "Environment, Safety and Health Protection Standards"
Order DOE 5480.6, "Safety of Department of Energy Owned Nuclear Reactors"
Order DOE 5480.11, "Occupational Radiation Protection"
Order DOE 5480.24, "Nuclear Criticality Safety"
Order DOE 5480.25, "Safety at Accelerator Facilities"
Order DOE 5484.1, "Environmental Protection, Safety and Health Protection Information Reporting Requirements"
Order DOE 5820.2A, "Radioactive Waste Management"

C.2.1.2 Energy Reorganization Act of 1974 (Public Law 93-438 (1974), as amended)

The Energy Reorganization Act of 1974 divided the former Atomic Energy Commission and created the Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission. The ERDA was responsible for radiation protection at its facilities, to provide for worker and public health, worker safety, and environmental protection. ERDA was abolished with the creation of the Department of Energy in 1980.

C.2.1.3 Department of Energy Organization Act of 1977 Public Law 95-91

The Department of Energy Organization Act created the Department of Energy (DOE) by combining the Energy Research & Development Administration, the Federal Energy Administration, Federal Power Commission, and part of the Department of Interior.

The DOE was intended to identify potential environmental, health, safety, socioeconomic, institutional, and technological issues associated with the development and use of energy sources. Through this Act, DOE retained the responsibilities and authorities—held by its predecessor agencies—to take actions necessary to protect the public from radiation associated with radioactive materials production, research, and development. DOE established requirements through a directives system that largely used DOE Orders as its regulatory procedures. With the passage of the Price-Anderson Act Amendments of 1990, DOE began converting its health and safety Orders to rules.

C.2.1.4 Uranium Mill Tailings Radiation Control Act of 1978, as amended

The Uranium Mill Tailings Radiation Control Act (UMTRCA) provides a program of assessment and remedial action at active and inactive uranium mill sites to control their tailings in a safe and environmentally sound manner and to reduce radiation hazards to the public residing in the vicinity of these sites. The DOE was directed to complete remedial action at 21 sites of inactive uranium mills.

C.2.1.5 West Valley Demonstration Project Act of 1980

This act authorized DOE to carry out a project at West Valley, New York to demonstrate solidification techniques which could be used for preparing high level radioactive waste for disposal. The Act provides for informal review and project consultation by the NRC.

C.2.1.6 Low-Level Waste Policy Act of 1980

This act established the policy that each State is responsible for providing for the disposal of low-level radioactive waste generated within its borders, except for waste from defense activities of

DOE or Federal research and development activities, and authorized States to enter into compacts to carry out this policy. DOE was required to take actions to assist the States in carrying out this policy.

C.2.1.7 Nuclear Waste Policy Act of 1982 (Public Law 97-425, 1983)

This Act gives DOE the responsibility to develop repositories and to establish a program of research, development, and demonstration for the disposal of high-level radioactive waste and spent nuclear fuel. Title to and custody of commercial low-level waste sites under certain conditions could be transferred to DOE.

C.2.1.8 Low-Level Waste Policy Amendments Act of 1985

This act amends the Low-Level Waste Policy Act of 1980 to improve the procedures for State compacts. It also assigns responsibility to the Federal government for the disposal of low-level waste generated or owned by the DOE, specific other Federally generated or owned wastes, and wastes with concentrations of radionuclides that exceed the limits established by the NRC for class C radioactive waste. The Act provides that all class C radioactive wastes designated as a Federal responsibility—those that result from activities licensed by the NRC—shall be disposed of in a facility licensed by the NRC. The Act also assigns responsibilities to DOE to provide financial and technical assistance to the States in carrying out the Act.

C.2.1.9 Waste Isolation Pilot Plant Land Withdrawal Act

The Waste Isolation Pilot Plant (WIPP) is a repository intended for the disposal of transuranic radioactive waste produced by defense activities. The Act establishes the following:

1) an isolated parcel of land for the WIPP
2) provisions concerning testing and limits on the quantities of waste which may be disposed at the WIPP
3) EPA certification of compliance with disposal standards

C.2.1.10 Price Anderson Act

C.2.2 Executive Orders

Executive Order (E.O.) 12580 delegates to various Federal officials the responsibilities vested in the President for implementing the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA).

C.2.3 DOE Regulations and Orders

C.2.3.1 10 CFR Part 835, "Occupational Radiation Protection"

This rule, which became effective on January 13, 1993, provides for the protection of radiation workers at DOE owned facilities. The requirements contained in Part 835 are generally similar to those in Order DOE 5480.11 and those used in NRC Regulations pertaining to the commercial nuclear industry. In addition to the rule, DOE issued a dozen implementation guides, including the "DOE Radiological Control Manual," (DOE/EH-0256T, Rv.1, April 1994).

C.2.3.2 Order DOE 5400.5, "Radiation Protection of the Public and the Environment"

This Order, issued in February 1990, contains DOE's requirements for ensuring the protection of the public from the hazards of radiation. This regulation includes dose limits for protection of the public and environment, plus requirements:

1) to apply the ALARA process—to reduce doses to the public as far below the release criterion as is practicable
2) to apply the best available control technology to liquid effluents
3) for control of property containing residual radioactive material

DOE 5400.5 is supported by numerous guidance documents, including those listed in this section.

DOE 5400.5 is the primary directive relating to the release of property subject to radiological contamination by DOE operations. DOE 5400.5 will be replaced by 10 CFR Part 834 and its guidance will be adopted for Part 834 when it is issued.

Under DOE 5400.5 and the guidance included in this section (C.2.3), DOE established requirements for a case-by-case review and approval for release of real or non-real property containing residual radioactive material. Authorized limits and measurement procedures must be developed by DOE before facilities can release property from their control. The principle requirement is to reduce doses to levels that are as low as practicable using the ALARA process and assuming realistic but conservative use scenarios that are not likely to underestimate dose. This requirement ensures that doses are as far below the primary dose limit (1 mSv/y [100 mrem/y]) as is reasonably achievable. Because the primary dose limit is for doses from all sources and pathways, authorized limits should be selected at levels below a DOE dose constraint of 0.3 mSv/y (30 mrem/y). However, the goal is to reduce doses under likely-use scenarios to a few fractions of a mSv/year or less.

In addition to the requirement to apply ALARA and the dose constraint, DOE also utilizes surface contamination guidelines similar to those in NRC Regulatory Guide 1.86 and the 40 CFR Part 192 soil concentration limits for radium and thorium. The ALARA requirement ensures that the 40 CFR Part 192 limits are appropriately used. DOE also permits the use of supplemental limits for situations where cleanups to authorized limits are not practicable or where the scenarios used to develop the authorized limits are not appropriate. DOE 5400.5 permits the release of property for restricted use and requires procedures to ensure these restrictions are maintained.

Most DOE remedial action and restoration activities are also subject to CERCLA. In such cases, DOE requirements are integrated into the CERCLA process.

The following sections describe the scope and importance of several guidance documents.

A. Residual Radioactive Material Control:

DOE/CH-8901, Manual for Implementing Residual Radioactive Material Guidelines - A Supplement to the U.S. Department of Energy Guidelines for Residual Radioactive Material at FUSRAP and SFMP Sites, Department of Energy, June 1989.

DOE Guidance Memorandum, "Unrestricted Release of Radioactively Contaminated Personal Property," J. Maher, DOE Office of Nuclear Safety, Mar. 15, 1984.

ANL/EAD/LD-2, Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD, Version 5.0, Published by Argonne National Laboratory and prepared by ANL and DOE staff, September 1993.

ANL/EAIS-8, Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil, Argonne National Laboratory, April 1993.

ANL/EAIS/TM-103, A Compilation of Radionuclide Transfer Factors for Plant, Meat, Milk and Aquatic Food Pathways and Suggested Default Values for the RESRAD Code, Argonne National Laboratory, August 1993.

PNL-8724, Radiation Dose Assessments to Support Evaluations of Radiological Control Levels for Recycling or Reuse of Material and Equipment, Pacific Northwest Laboratory, July 1995.

ANL/EAD.LD-3, RESRAD-Build: A Computer Model for Analyzing the Radiological Doses Resulting from the Remediation and Occupancy of Buildings Contaminated with Radioactive Material, Argonne National Laboratory, November 1994.

B. ALARA

DOE Guidance: DOE Guidance on the Procedures in Applying the ALARA Process for Compliance with DOE 5400.5, Department of Energy, Office of Environmental Guidance, March 8, 1991.

ANL/EAD/LD-2, Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD, Version 5.0, Chapters 1 and 5 and App. M, September 1993.

C. Measurement and Data Reporting

DOE Manual for use and Comment, Environmental Implementation Guide for Radiological Survey Procedures, Department of Energy, Office of Environmental Guidance, Nov. 1992.

DOE/EH-0173T, Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance, Department of Energy, Jan. 1991.

D. Dose Factors

DOE/EH-0071, Internal Dose Conversion Factors for Calculation of Dose to the public, DOE, July 1988. DOE currently recommends use of EPA-520-1-88-020, Federal Guidance Report No. 11, Limiting Radionuclide Intake and Air Concentrations and Dose Conversion Factors for Inhalation, Submersion and Ingestion, Environmental Protection Agency, Sept. 1988, as an alternative to DOE/EH-0071.

DOE/EH-0070, External Dose-Rate Conversion Factors for Calculation of Dose to the Public, DOE, July 1988. DOE currently recommends use of EPA 402-R-93-081, Federal Guidance Report No. 12, External Exposure to Radionuclides in Air, Water and Soil, Environmental Protection Agency, Sept. 1993, as an alternative to DOE/EH-0070.

E. Liquid Effluents

Implementation Guidance for DOE 5400.5, Section II.3 (Management and Control of Radioactive Materials in Liquid Discharges and the Phaseout of Soil Columns), DOE Office of Environment, June 1992.

C.2.3.3 Order DOE 5820.2A, "Radioactive Waste Management"

Order DOE 5820.2A establishes the policies, guidelines, and requirements by which the DOE manages its radioactive and mixed waste and contaminated facilities. The Order implements DOE's responsibilities and authorities for prediction of public and worker health and safety and

the environment under the Atomic Energy Act. It contains the requirements for management and disposal of high-level waste, transuranic waste, low-level waste, NARM waste, and for the decommissioning of radioactively contaminated facilities.

A. High-level Waste

The Order specifies: (1) requirements for storage operations including requirements for waste characterization, transfer operations, monitoring, surveillance, and leak detection, and (2) specifies that disposal shall be in accordance with the requirements of the Nuclear Waste Policy Act of 1982.

B. Transuranic Waste

The Order requires waste to be certified in compliance with the Waste Isolation Pilot Plant-Waste Acceptance Criteria and sent to the WIPP. There are requirements for waste classification, waste generation and treatment, waste certification, waste packaging, temporary storage, transportation and shipping, and interim storage. There are provisions for use of the WIPP, and for assessing the disposition of previously buried transuranic-contaminated wastes.

C. Low-level Waste

The Order specifies performance objectives which assure that external exposure waste concentrations of radioactive material—which may be released into surface water, ground water, soil, plants, and animals—result in an effective dose equivalent that does not exceed 0.25 mSv/y (25 mrem/y) to a member of the public. Releases to the atmosphere shall meet the requirements of 40 CFR Part 61. Reasonable efforts should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable. Radiological performance assessments are required for the disposal of waste for the purpose of demonstrating compliance with these performance objectives.

For low-level waste, there are also requirements on waste generation, waste characterization, waste acceptance criteria, waste treatment, and long term storage. The Order includes additional disposal requirements concerning disposal facility and disposal site design and waste characteristic, site selection, facility operations, site closure and post closure, and environmental monitoring.

D. NARM Waste

For management of Naturally-Occurring and Accelerator-Produced Radioactive Materials (NARM) and 11(e)(2) byproduct materials (the tailings or wastes resulting from the concentration of uranium or thorium), the order specifies that storage and disposal shall be

consistent with the requirements of the residual radioactive material guidelines contained in 40 CFR 192.

E. Decommissioning of Radioactively Contaminated Facilities

For the decommissioning of contaminated facilities, the order requires DOE organizations to develop and document decommissioning programs which include provisions for surveillance and maintenance. There are requirements for facility design, post-operational activities, characterization, and environmental review.

C.3 NRC Regulations and Requirements

C.3.1 NRC's Mission and Statutory Authority

The mission of the U.S. Nuclear Regulatory Commission (NRC) is to ensure adequate protection of the public health and safety, the common defense and security, and the environment in the use of nuclear materials in the United States. The NRC's scope of responsibility includes regulation of commercial nuclear power reactors; nonpower research, test, and training reactors; fuel cycle facilities; medical, academic, and industrial uses of nuclear materials; and the storage and disposal of nuclear materials and waste.

The NRC is an independent agency created by the Energy Reorganization Act of 1974. This Act abolished the Atomic Energy Commission (AEC), moved the AEC's regulatory function to NRC, and, along with the Atomic Energy Act of 1954, as amended, provides the foundation for regulation of the nation's commercial nuclear power industry.

NRC regulations are issued under the United States Code of Federal Regulations (CFR) Title 10, Chapter 1. Principal statutory authorities that govern NRC's work are:

- Atomic Energy Act of 1954, as amended
- Energy Reorganization Act of 1974, as amended
- Uranium Mill Tailings Radiation Control Act of 1978, as amended
- Nuclear Non-Proliferation Act of 1978
- Low-Level Radioactive Waste Policy Act of 1980
- West Valley Demonstration Project Act of 1980
- Nuclear Waste Policy Act of 1982
- Low-Level Radioactive Waste Policy Amendments Act of 1985
- Diplomatic Security and Anti-Terrorism Act of 1986
- Nuclear Waste Policy Amendments Act of 1987
- Solar, Wind, Waste and Geothermal Power Production Incentives Act of 1990
- Energy Policy Act of 1992

The Atomic Energy Act of 1954, as amended, allows the NRC to issue orders to both licensees and persons not licensed by the NRC. NRC orders may be a means of compelling decommissioning at sites where the license has been terminated or at sites that were not previously licensed but currently contain radioactive material that is under the jurisdiction of the NRC.

The NRC and its licensees share a common responsibility to protect the public health and safety. Federal regulations and the NRC regulatory program are important elements in the protection of the public. NRC licensees, however, have the primary responsibility for the safe use of nuclear materials.

C.3.2 NRC Criteria for Decommissioning

This section of the survey manual contains information on the existing cleanup criteria for decommissioning sites regulated by the NRC. Additional cleanup criteria established by State and local governments may also be applicable at NRC-licensed sites at the time of decommissioning.

NRC's requirements for decommissioning and license termination are contained in 10 CFR 30.36, 40.42, 50.82, 70.38, and 72.54. The radiological criteria for license termination are contained in 10 CFR 20.1401 through 1406 (62 FR 39058, July 21, 1997).

Prior to the adoption of the current regulations on radiological criteria for license termination, the Commission's position on residual contamination criteria, site characterization, and other related decommissioning issues was outlined in a NRC document entitled "Action Plan to Ensure Timely Cleanup of Site Decommissioning Management Plan Sites," which was published in the Federal Register on April 6, 1993 (57 FR 13389). Other documents that were used in the past and which may continue to have some applicability in special cases include:

"Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material From Ores Processed Primarily for Their Source Material Content" (10 CFR 40, Appendix A) and Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings (40 CFR 192, Subparts D and E)

> These regulations, issued by the NRC and EPA, establish technical criteria related to the operation, decontamination, decommissioning, and reclamation of uranium or thorium mills and mill tailings. Both regulations provide design requirements for closure of the mill's waste disposal area, which requires an earthen cover over tailings or waste piles to control radiological hazards from uranium and thorium tailings for 200 to 1,000 years, according to Technical Criterion 6 of Appendix A to 10 CFR Part 40.

The principal radiological hazards from uranium milling operations and mill tailings disposal are radon from uranium and thorium daughters. The atmospheric release rates of these gaseous radionuclides to the atmosphere are limited to an average rate of 0.7 Bq (20 pCi) per square meter per second. This rate is applicable to any portion of a licensed or disposal site unless land areas do not contain radium concentrations—averaged over 100 square meters—greater than: (i) 0.2 Bq/g (5 pCi/g) of radium averaged over the first 15 centimeters below the surface, and (ii) 0.6 Bq/g (15 pCi/g) of radium averaged over 15-centimeter thick layers more than 15 centimeters below the surface.

Criterion 6 allows radon release rates to be averaged over a period of at least 1 year (but much less than 100 years) to account for the wide variability in atmospheric radon concentrations over short time periods and seasons. In addition, this criterion applies only to emissions from uranium daughters and does not include radon emissions from earthen materials used to cover the tailings piles. If appropriate, radon emissions from cover materials are evaluated when developing a closure plan for each site to account for this additional contribution from naturally occurring radon. However, direct gamma exposure rates from tailings or wastes should be reduced to background levels according to this standard.

C.3.3 NRC Decommissioning Process and Staff Plans for Implementing Survey Procedures in this Manual

NRC licensees are required to conduct radiation surveys of the premises where the licensed activities were conducted and submit a report describing the survey results. The survey process follows requirements contained in 10 CFR 30.36, 40.42, 50.82, 70.38, and 72.54, which pertain to decommissioning of a site and termination of a license. This process leads to the unrestricted release of a site; however, many of the requirements may not be necessary if the licensee demonstrates that the premises are suitable for release in some other manner. Each year, the NRC staff routinely evaluates licensee requests to discontinue licensed operations. The majority of these requests are straightforward, requiring little, if any, site remediation before radiological surveys are conducted and evaluated. However, some NRC sites require substantial remediation because buildings and lands contain nonroutine amounts of radiological contamination. Radiological surveys may also be performed by the NRC at sites where there is not a license.

The NRC decommissioning process for a site requiring substantial remediation can be described by the activities listed below:

- licensee notifies the NRC they intend to decommission all or part of the site
- site characterization, including preparation of the characterization plan and performance of site characterization
- development and submission of decommissioning plan

- NRC review and approval of decommissioning plan
- performance of decommissioning actions described in the plan
- performance of termination survey and submittal of termination survey report
- NRC performance and documentation of confirmatory survey
- NRC termination of license

The NRC staff plans to use the information contained in this manual as primary guidance for conducting radiological surveys of routine licensee requests for license termination and nonroutine license termination requests that require more extensive decommissioning actions. Supplementary guidance may be used by the NRC staff to assist licensees in conducting such surveys or aid the NRC staff in evaluating licensee's survey plans and survey results to determine compliance with decommissioning criteria. Examples of supplementary guidance include NRC Information Notices, Bulletins, Generic Letters, Branch Technical Positions, NUREG reports, Regulatory Guides, and other regulatory documents that transmit NRC requirements and guidance.

C.4 DOD Regulations and Requirements

The Department of Defense (DOD) consists of four primary military services: the United States Air Force, the United States Army, the United States Navy, and the United States Marine Corps.

DOD installations use sources of ionizing radiation and support radiation protection programs for the control of these radioactive materials. As a Federal agency, the DOD complies with all applicable environmental regulations under the Federal Facilities Compliance Act of 1992.

C.4.1 DOD Sources of Ionizing Radiation

DOD's list of radioactive materials includes:

- Special nuclear material such as plutonium or enriched uranium
- Source material such as uranium or thorium
- Byproduct material such as any radioactive material yielded in or made radioactive by exposure to radiation incident to the process of producing special nuclear material
- Naturally occurring or accelerator-produced radioactive material (NARM), such as radium, and not classified as source material
- Materials containing induced or deposited radioactivity

Ionizing Radiation Producing Devices: Electronic devices that are capable of emitting ionizing radiation. Examples are linear accelerators, cyclotrons, radiofrequency generators that use klystrons or magnetrons, and other electron tubes that produce x-rays. These devices may have

components that contain radioactive material or they may induce radioactivity in certain other materials.

C.4.2 Commodities Containing Radioactive Material Within the DOD System

The DOD uses a variety of manufactured items (commodities) incorporating in whole or in part both sealed and unsealed radioactive material. A sealed source is any radioactive material that is permanently bound or fixed in a capsule or matrix designed to prevent the release or dispersal of such material under the most severe conditions encountered in normal use.

Ionizing radiation is used directly in DOD systems as calibration and check sources for RADIAC or other survey-type instruments, as a source of radioluminescence in meters and gauges, as an ionization source in various devices, and as radiographic sources.

Indirectly, ionizing radiation may be emitted from a DOD material system as natural radioactivity or induced radioactivity incorporated into material or a component of the system.

Specific examples of commodities include instrument calibration sources, luminescent compasses and exit signs, certain electron tubes and spark gaps, depleted uranium counterweights and munitions, and magnesium-thorium aircraft components.

C.4.3 Licensed Radioactive Material

Licensed radioactive material is source, special nuclear, or byproduct material received, stored, possessed, used, or transferred under a specific or general license issued by the NRC or an NRC Agreement State.

Radioactive material licensed or controlled by the individual military services:

- The Department of the Air Force has been designated by the NRC, through the issuance of a Master Materials License, regulatory authority for the receipt, possession, distribution, use, transportation, transfer, and disposal of radioactive material at Air Force activities. The Air Force Radioisotope Committee was established to provide administrative control of all radioactive material used in the Air Force except for reactors and associated radioactivity, nuclear weapons, and certain components of weapons delivery systems. Air Force Radioactive Material Permits are used to maintain this control.

- The Department of the Army, through the issuance of NRC specific licenses to Army installations and activity commanders, maintains the regulatory authority for the receipt, possession, distribution, use, transportation, transfer, and disposal of radioactive material

at Army activities. In addition, within the Department of the Army, radioactive material classified as NARM may be used under a Department of the Army Radioactive Material Authorization (DARA) issued by the Army Material Command (AMC) or the Office of The Army Surgeon General. A Department of the Army Radiation Permit is required for use, storage, possession, and disposal of radiation sources by non-Army agencies (including contractors) on Army installations.

- The Department of the Navy is designated by the NRC to have—through the issuance of a Master Materials License—regulatory authority for the receipt, possession, distribution, use, transportation, transfer, and disposal of radioactive material at Navy and Marine Corps activities. The Navy Radiation Safety Committee was established to provide administrative control of all radioactive material used in the Navy and Marine Corps except for nuclear propulsion reactors and associated radioactivity, nuclear weapons, and certain components of weapons delivery systems. Navy Radioactive Material Permits are used to maintain this control.

C.4.4 Other Controlled Radioactive Material

Certain radioactive material on DOD installations may not be controlled or regulated by either the NRC or the DOE. However, during Base Realignment and Closure actions, DOD installation property which is identified to be returned to civilian use may have the potential for radioactive contamination by such material. The DOD complies with applicable State limits, guidelines, and procedures for this material. The methodologies and technical approaches for environmental radiological surveys outlined in this manual will provide guidance for dealing with issues concerning this material.

Naturally Occurring and Accelerator-Produced Radioactive Material

- Naturally occurring and accelerator-produced radioactive material (NARM) is controlled and regulated by the individual military services, as is similarly done by certain States for corporations and other users residing within their boundaries.

Special Nuclear Material Used in Military Applications

- Special nuclear material used in military applications is a unique category of radioactive material. This may be buried as radioactive waste on DOD installations, used in military weapons or utilization facilities, or used in nuclear reactors involving military applications on DOD installations. Radioactive material used or associated with weapons systems or reactors associated with such military applications is exempt from NRC and State regulations under Section 91b, Chapter 9, Military Application of Atomic Energy, Atomic Energy Act of 1954.

C.4.5 DOD Regulations Concerning Radiation and the Environment

The DOD, with its global mission, supports several directives and instructions concerning environmental compliance. The individual military services have regulations implementing these directives and instructions. The documents describing these regulations are used as guidance in developing environmental radiological surveys within DOD.

The DOD and each military service also have specific regulations addressing the use of radioactive sources and the development of occupational health programs and radiation protection programs. These regulations may help in identifying potential locations and sources of radioactive contamination on DOD installations.

C.4.6 DOD Regulations and Requirements

Regulations and Requirements Concerning Development of Environmental Radiological Surveys

1. DOD Directive 4165.60, Solid and Hazardous Waste Management-Collection, Disposal, Resource Recovery, and Recycling Program.
2. DOD Directive 4210.15, Hazardous Material Pollution Prevention.
3. DOD Directive 5100.50, Protection and Enhancement of Environmental Quality.
4. DOD Directive 6050.1, Environmental Effects in the United States of Department of Defense Actions.
5. DOD Directive 6050.7, Environmental Effects Abroad of Major Department of Defense Actions.
6. DOD Directive 6050.8, Storage and Disposal of Non-DOD-Owned-Hazardous or Toxic Materials on DOD Installations.
7. DOD Instruction 4120.14, Environmental Pollution Prevention, Control, and Abatement.
8. DOD Instruction 5100.5, Protection and Enhancement of Environmental Quality.

Regulations and Requirements Concerning Use of Radioactive Sources and Development of Occupational Health Programs and Radiation Protection Programs:

1. DOD Instruction 6055.5-M, Occupational Health Surveillance Manual.
2. DOD Instruction 6055.8, Occupational Radiation Protection Program.

Examples of Air Force Instructions (AFIs):

1. AFI 40-201, Managing Radioactive Materials in the Air Force.
2. AFI 32-7020, Environmental Restoration Program.
3. AFI 32-7066, Environmental Baseline and Close-out Surveys in Real Estate Transactions.

Examples of Army Regulations (ARs):

1. AR 40-5, Preventive Medicine.
2. AR 40-14, Occupational Ionizing Radiation Personnel Dosimetry.
3. AR 40-10, Health Hazard Assessment Program in Support of the Army Materiel Acquisition Decision Process.
4. AR 200-1, Environmental Protection and Enhancement.
5. AR 200-2, Environmental Effects of Army Actions.
6. AR 385-11, Ionizing Radiation Protection (Licensing, Control, Transportation, Disposal, and Radiation Safety).
7. AR 385-30, Safety Color Code Markings and Signs.
8. AR 700-64, Radioactive Commodities in the DOD Supply System.
9. AR 750-25, Army Test, Measurement, and Diagnostic Equipment (TMDE) Calibration and Repair Support Program.
10. TB MED 521, Management and Control of Diagnostic X-Ray, Therapeutic X-Ray, and Gamma Beam Equipment.
11. TB MED 522, Control of Health Hazards from Protective Material Used in Self-Luminous Devices.
12. TB MED 525, Control of Hazards to Health from Ionizing Radiation Used by the Army Medical Department.
13. TB 43-180, Calibration and Repair Requirements for the Maintenance of Army Materiel.
14. TB 43-0108, Handling, Storage, and Disposal of Army Aircraft Components Containing Radioactive Material.
15. TB 43-0116, Identification of Radioactive Items in the Army.
16. TB 43-0122, Identification of U.S. Army Communications-Electronic Command Managed Radioactive items in the Army.
17. TB 43-0141, Safe Handling, Maintenance, Storage, and Disposal of Radioactive Commodities Managed by U.S. Army Troop Support and Aviation Material Readiness Command (Including Aircraft Components).
18. TB 43-0197, Instructions for Safe Handling, Maintenance, Storage, and Disposal of Radioactive Items Managed by U.S. Army Armament Material Command.
19. TB 43-0216, Safety and Hazard Warnings for Operation and Maintenance of TACOM Equipment.
20. TM 3-261, Handling and Disposal of Unwanted Radioactive Material.
21. TM 55-315, Transportability Guidance for Safe Transport of Radioactive Materials.

Examples of Navy Regulations:

1. NAVMED P-5055, Radiation Health Protection Manual.
2. NAVSEA SO420-AA-RAD-010, Radiological Affairs Support Program (RASP) Manual.
3. OPNAV 6470.3, Navy Radiation Safety Committee.

4. NAVSEA 5100.18A, Radiological Affairs Support Program.
5. OPNAV 5100.8G, Navy Safety and Occupational Safety and Health Program.
6. NAVMEDCOM 6470.10, Initial Management of Irradiated or Radioactively Contaminated Personnel.
7. OPNAV 3710.31, Carrying Hazardous Materials; Operational Procedures.
8. NAVSUP 5101.11, Procedures for the Receipt, Storage, and Handling of Radioactive Material Shipments.
9. NAVSUP 5101.6, Procedures for the Requisitioning, Labeling, Handling, Storage, & Disposal of Items Which Contain Radioactive By-Product Material.
10. NAVSUP 4000.34, Radioactive Commodities in the DOD Supply System.
11. NAVSEA 9639.1, Radioluminescent Sources and Radioactively Contaminated Equipment Aboard Inactive Naval Ships and Craft.
12. NAVSUP 4510.28, Special Restrictions on Issue and Disposal of Radiological Control Materials.
13. NAVMED 6470.7, Procedures and Responsibilities for Use of Radioactive Materials at NAVMED Activities.

C.5 State and Local Regulations and Requirements

An Agreement State is a State that has signed an agreement with the NRC allowing the State to regulate the use of radioactive materials—*i.e.*, specifically Atomic Energy Act materials—within that State. Table C.2 lists the Agreement States as of April 15, 2000 (see Appendix L for contacts and addresses). Each Agreement State provides regulations governing the use of radioactive materials that may relate to radiation site investigations.[3] Table C.3 lists the States that regulate naturally occurring radioactive material (NORM) as of January 1, 2000 (PGA 2000). A number of other States are in the process of developing regulations governing the use of NORM. The decision maker should check with the State to ensure compliance with all applicable regulations.

[3] A current list of agreement states, addresses, and contacts can be obtained through the U.S. Nuclear Regulatory Commission on the Internet on the State Program Directory page operated by the Oak Ridge National Laboratory at http://www.hsrd.ornl.gov/nrc/asframe.htm.

Table C.2 Agreement States		
Alabama	Louisiana	North Carolina
Arizona	Maine	North Dakota
Arkansas	Maryland	Ohio
California	Massachusetts	Oregon
Colorado	Mississippi	Rhode Island
Florida	Nebraska	South Carolina
Georgia	Nevada	Tennessee
Illinois	New Hampshire	Texas
Iowa	New Mexico	Utah
Kansas	New York	Washington
Kentucky		

Table C.3 States That Regulate Diffuse NORM		
Alabama (proposed)	Michigan	Oklahoma (proposed)
Arkansas	Mississippi	Oregon
Colorado (proposed)	New Jersey	South Carolina
Georgia	New Mexico	Texas
Illinois (proposed)	North Dakota	Utah
Louisiana	Ohio	

APPENDIX D

THE PLANNING PHASE OF THE DATA LIFE CYCLE

The planning phase of the Data Life Cycle is carried out using the Data Quality Objectives (DQO) Process. The DQO Process is a series of planning steps based on the scientific method for establishing criteria for data quality and developing survey designs (EPA 1994a, 1987b, 1987c). The level of effort associated with planning is based on the complexity of the survey. Large, complicated sites generally receive a significant amount of effort during the planning phase, while smaller sites may not require as much planning effort.

Planning radiological surveys using the DQO Process can improve the survey effectiveness and efficiency, and thereby the defensibility of decisions. It also can minimize expenditures related to data collection by eliminating unnecessary, duplicative, or overly precise data. The use of the DQO Process assures that the type, quantity, and quality of environmental data used in decision making will be appropriate for the intended application. It provides systematic procedures for defining the criteria that the survey design should satisfy, including when and where to perform measurements, the level of decision errors for the survey, and how many measurements to perform.

The expected output of planning a survey using the DQO Process is a quality assurance project plan (QAPP). The QAPP integrates all technical and quality aspects of the Data Life Cycle, and defines in detail how specific quality assurance and quality control activities will be implemented during the survey.

The DQO Process provides for early involvement of the decision maker and uses a graded approach to data quality requirements. This graded approach defines data quality requirements according to the type of survey being designed, the risk of making a decision error based on the data collected, and the consequences of making such an error. This approach provides a more effective survey design combined with a basis for judging the usability of the data collected.

DQOs are qualitative and quantitative statements derived from the outputs of the DQO Process that:

- clarify the study objective
- define the most appropriate type of data to collect
- determine the most appropriate conditions for collecting the data
- specify limits on decision errors which will be used as the basis for establishing the quantity and quality of data needed to support the decision

The DQO Process consists of seven steps, as shown in Figure D.1. The output from each step influences the choices that will be made later in the Process. Even though the DQO Process is depicted as a linear sequence of steps, in practice it is iterative; the outputs of one step may lead to reconsideration of prior steps as illustrated in Figure D.2. For example, defining the survey unit boundaries may lead to classification of the survey unit, with each area or survey unit having a different decision statement. This iteration is encouraged since it ultimately leads to a more efficient survey design. The first six steps of the DQO Process produce the decision performance criteria that are used to develop the survey design. The final step of the Process develops a survey design based on the DQOs. The first six steps should be completed before the final survey design is developed, and every step should be completed before data collection begins.

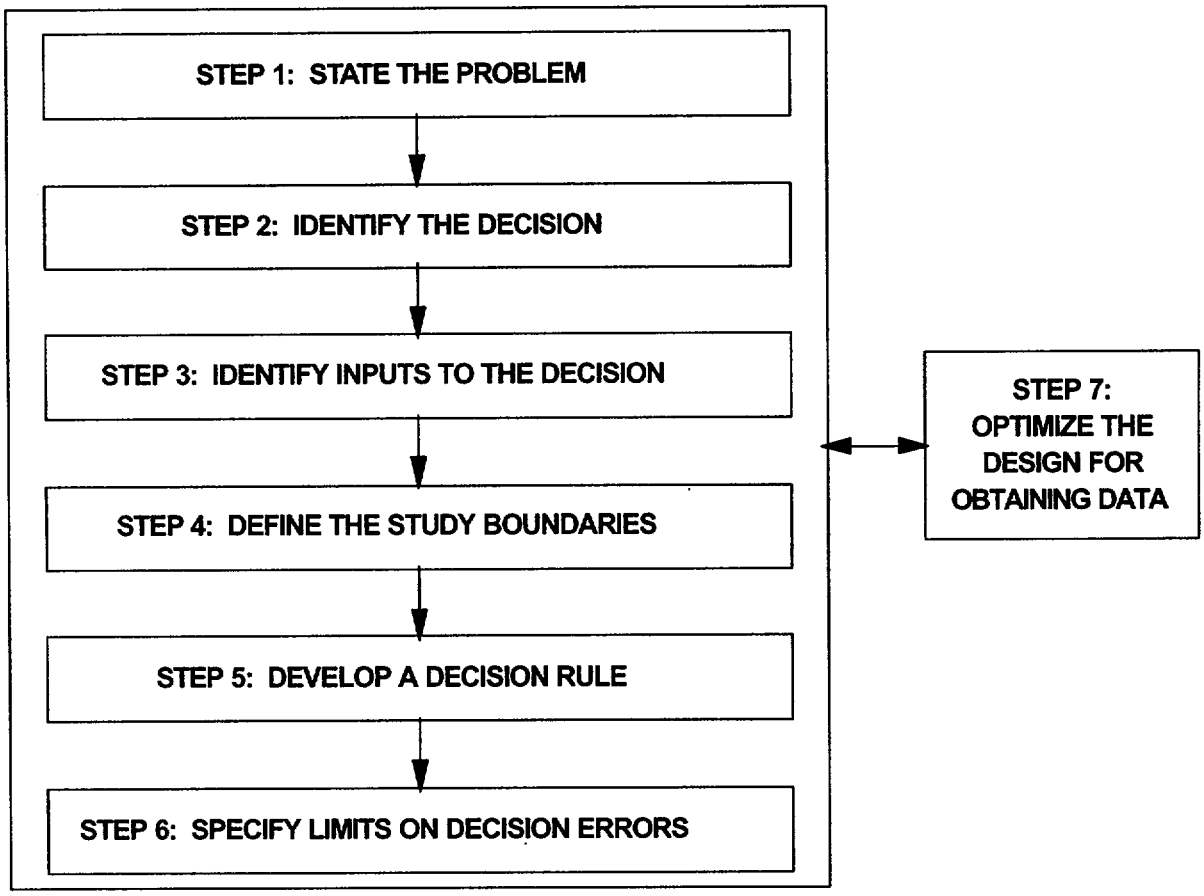


Figure D.1 The Data Quality Objectives Process

When the DQO Process is used to design a survey, it helps ensure that planning is performed properly the first time and establishes measures of performance for the data collector (implementation) and the decision maker (assessment) during subsequent phases of the Data Life Cycle. DQOs provide up-front planning and define decision maker/data collector relationships by presenting a clear statement of the decision maker's needs. This information is recorded in the QAPP.

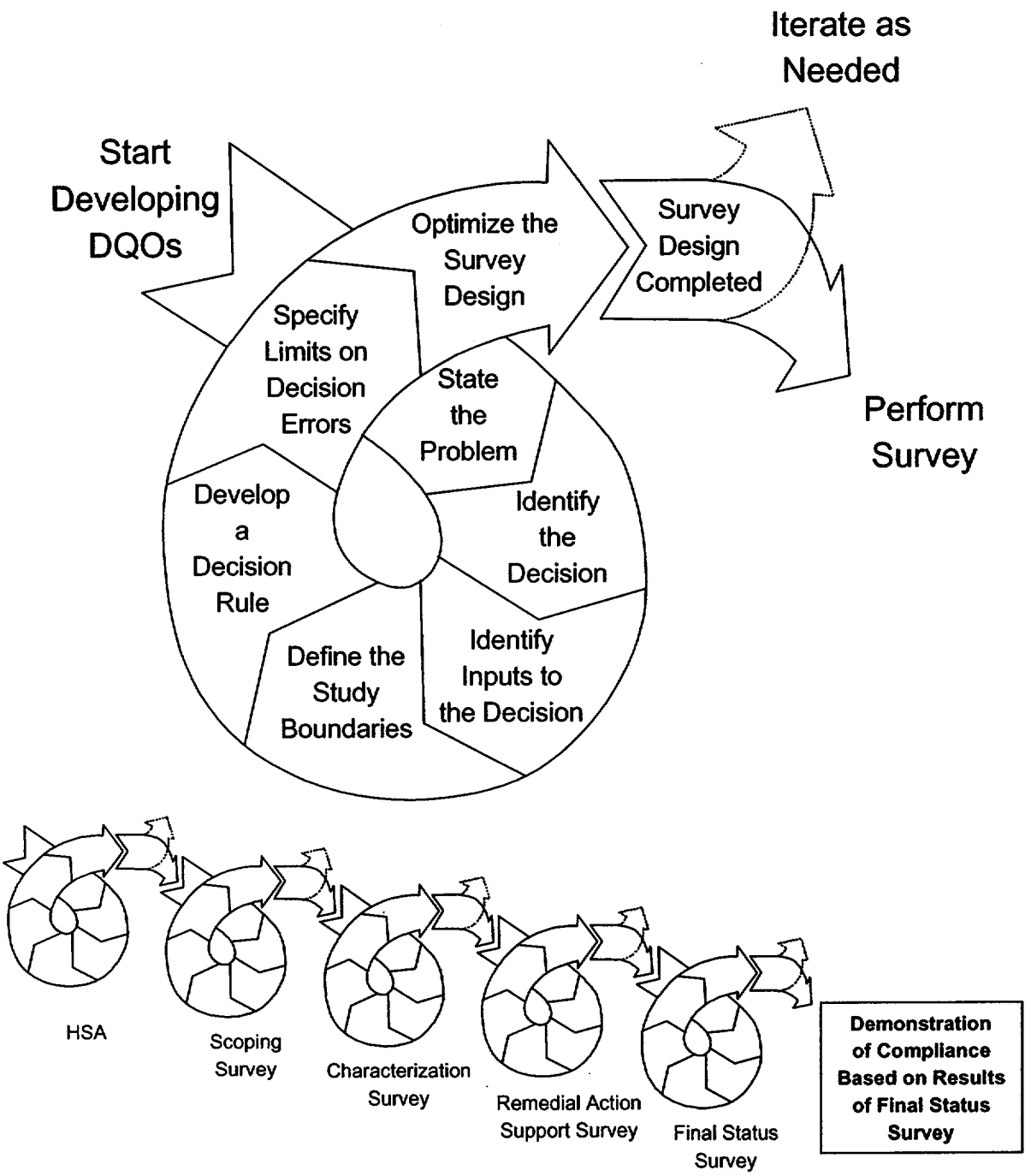


Figure D.2 Repeated Applications of the DQO Process Throughout the Radiation Survey and Site Investigation Process

DQOs for data collection activities describe the overall level of uncertainty that a decision maker is willing to accept for survey results. This uncertainty is used to specify the quality of the measurement data required in terms of objectives for precision, accuracy, representativeness, comparability, and completeness. These objectives are presented in detail in Section 9.3.2 and Appendix N.

The DQO Process is a flexible planning tool that can be used more or less intensively as the situation requires. For surveys that have multiple decisions, such as characterization or final status surveys, the DQO Process can be used repeatedly throughout the performance of the survey. Decisions made early in decommissioning are often preliminary in nature. For this reason, a scoping survey may only require a limited planning and evaluation effort. As the site investigation process nears conclusion the necessity of avoiding a decision error becomes more critical.

The following sections briefly discuss the steps of the DQO Process, especially as they relate to final status survey planning, and list the outputs for each step in the process. The outputs from the DQO Process should be included in the documentation for the survey plan.

D.1 State the Problem

The first step in any decision making process is to define the problem so that the focus of the survey will be unambiguous. Since many sites or facilities present a complex interaction of technical, economic, social, and political factors, the success of a project is critically linked to a complete but uncomplicated definition of the problem .

There are four activities associated with this step:

- identifying members of the planning team and stakeholders
- identifying the primary decision maker or decision-making method
- developing a concise description of the problem
- specifying available resources and relevant deadlines for the study

The expected outputs of this step are:

- a list of the planning team members and identification of the decision maker
- a concise description of the problem
- a summary of available resources and relevant deadlines for the survey

For a final status survey, examples of planning team members and stakeholders are described in Section 3.2. A description of the problem would typically involve the release of all or some portion of a site to demonstrate compliance with a regulation. The resources and deadlines are typically identified on a site-specific basis.

D.2 Identify the Decision

The goal of this step is to define the question that the survey will attempt to resolve and identify alternative actions that may be taken based on the outcome of the survey. The combination of these two elements is called the decision statement. The decision statement would be different for each type of survey in the Radiation Survey and Site Investigation Process, and would be developed based on the survey objectives described in Chapter 5.

There are four activities associated with this step in the DQO Process:

- identifying the principal study question
- defining the alternative actions that could result from resolution of the principal study question
- combining the principal study question and the alternative actions into a decision statement
- organizing multiple decisions

The expected output from this step is a decision statement that links the principal study question to possible solutions to the problem.

For a final status survey, the principal study question could be: "Is the level of residual radioactivity in the survey units in this portion of the site below the release criterion?" Alternative actions may include further remediation, re-evaluation of the modeling assumptions used to develop the DCGLs, re-assessment of the survey unit to see if it can be released with passive controls, or a decision not to release the survey unit. The decision statement may be: "Determine whether or not all the survey units in this portion of the site satisfy the release criterion."

D.3 Identify the Inputs to the Decision

Collecting data or information is necessary to resolve most decision statements. In this step, the planning team focuses on the information needed for the decision and identifies the different types of information needed to resolve the decision statement.

The key activities for this step include:

- Identifying the information required to resolve the decision statement. Ask general questions such as: "Is information on the physical properties of the site required?" or: "Is information on the chemical characteristics of the radionuclide or the matrix required?" Determine which environmental variables or other information are needed to resolve the decision statement.

- Determining the sources for each item of information. Identify and list the sources for the required information.
- Identifying the information needed to establish the action level or the derived concentration guideline level (DCGL) based on the release criterion. The actual numerical value will be determined in Step 5 (*i.e.*, Section D.5).
- Confirming that appropriate measurement methods exist to provide the necessary data. A list of potentially appropriate measurement techniques should be prepared based on the information requirements determined previously in this step. Field and laboratory measurement techniques for radionuclides are discussed in Chapters 6 and 7 of this manual. Information on using field and laboratory equipment, their detection limits and analytical costs are listed in Appendix H. This performance information will be used in Steps 5 and 7 of the DQO Process.

The expected outputs of this step are:

- a list of informational inputs needed to resolve the decision statement
- a list of environmental variables or characteristics that will be measured

For the final status survey, the list of information inputs generally involves measurements of the radioactive contaminants of concern in each survey unit. These inputs include identifying survey units, classifying survey units, identifying appropriate measurement techniques including measurement costs and detection limits, and whether or not background measurements from a reference area or areas need to be performed. The list of environmental variables measured during the final status survey is typically limited to the level of residual radioactivity in the affected media for each survey unit.

D.4 Define the Boundaries of the Study

During this step the planning team should develop a conceptual model of the site based on existing information collected in Step 1 of the DQO Process or during previous surveys. Conceptual models describe a site or facility and its environs, and present hypotheses regarding the radionuclides present and potential migration pathways. These models may include components from computer models, analytical models, graphic models, and other techniques. Additional data collected during decommissioning are used to expand the conceptual model.

The purpose of this step is to define the spatial and temporal boundaries that will be covered by the decision statement so data can be easily interpreted. These attributes include:

- spatial boundaries that define the physical area under consideration for release (site boundaries)

- spatial boundaries that define the physical area to be studied and locations where measurements could be performed (actual or potential survey unit boundaries)
- temporal boundaries that describe the time frame the study data represents and when measurements should be performed
- spatial and temporal boundaries developed from modeling used to determine DCGLs

There are seven activities associated with this step:

- specifying characteristics that define the true but unknown value of the parameter of interest
- defining the geographic area within which all decisions must apply
- when appropriate, dividing the site into areas or survey units that have relatively homogeneous characteristics
- determining the time frame to which the decision applies
- determining when to collect data
- defining the scale of decision making
- identifying any practical constraints on data collection

The expected outputs of this step are:

- a detailed description of the spatial and temporal boundaries of the problem (a conceptual model)
- any practical constraints that may interfere with the full implementation of the survey design

Specifying the characteristics that define the true but unknown value of the parameter of interest for the final status survey typically involves identifying the radionuclides of concern. If possible, the physical and chemical form of the radionuclides should be described. For example, describing the residual radioactivity in terms of total uranium is not as specific or informative as describing a mixture of uraninite (UO_2) and uranium metaphosphate ($U(PO_3)_4$) for natural abundances of ^{234}U, ^{235}U, and ^{238}U.

As an example, the study boundary may be defined as the property boundary of a facility or, if there is only surface contamination expected at the site, the soil within the property boundary to a depth of 15 cm. When appropriate (typically during and always before final status survey design), the site is subdivided into survey units with relatively homogeneous characteristics based on information collected during previous surveys. The radiological characteristics are defined by the area classification (Class 1, Class 2, or Class 3) while the physical characteristics may include structures vs. land areas, transport routes vs. grassy areas, or soil types with different radionuclide transfer characteristics.

The time frame to which the final status survey decision applies is typically defined by the regulation. For example: "The data are used to reflect the condition of radionuclides leaching into ground water over a period of 1,000 years." Temporal boundaries may also include seasonal conditions such as winter snow cover or summer drought that affect the accessibility of certain media for measurement.

For the final status survey, the smallest, most appropriate subsets of the site for which decisions will be made are defined as survey units. The size of the survey unit and the measurement frequency within a survey unit are based on classification, site-specific conditions, and relevant decisions used during modeling to determine the DCGLs.

D.5 Develop a Decision Rule

The purpose of this step is to define the parameter of interest, specify the action level (or DCGL), and integrate previous DQO outputs into a single statement that describes a logical basis for choosing among alternative actions.

There are three activities associated with this step:

- specifying the statistical parameter that characterizes the parameter of interest
- specifying the action level for the study
- combining the outputs of the previous DQO steps into an "if...then..." decision rule that defines the conditions that would cause the decision maker to choose among alternative actions

Certain aspects of the site investigation process, such as the HSA, are not so quantitative that a statistical parameter can be specified. Nevertheless, a decision rule should still be developed that defines the conditions that would cause the decision maker to choose among alternatives.

The expected outputs of this step are:

- the parameter of interest that characterizes the level of residual radioactivity
- the action level
- an "if...then..." statement that defines the conditions that would cause the decision maker to choose among alternative actions

The parameter of interest is a descriptive measure (such as a mean or median) that specifies the characteristic or attribute that the decision maker would like to know about the residual contamination in the survey unit.

The mean is the value that corresponds to the "center" of the distribution in the sense of the "center of gravity" (EPA 1989a). Positive attributes of the mean include: 1) it is useful when the action level is based on long-term, average health effects, 2) it is useful when the population is uniform with relatively small spread, and 3) it generally requires fewer samples than other parameters of interest. Negative attributes include: 1) it is not a very representative measure of central tendency for highly skewed distributions, and 2) it is not useful when a large proportion of the measurements are reported as less than the detection limit (EPA 1994a).

The median is also a value that corresponds to the "center" of a distribution, but where the mean represents the center of gravity the median represents the "middle" value of a distribution. The median is that value such that there are the same number of measurements greater than the median as less than the median. The positive attributes of the median include: 1) it is useful when the action level is based on long-term, average health effects, 2) it provides a more representative measure of central tendency than the mean for skewed populations, 3) it is useful when a large proportion of the measurements are reported as less than the detection limit, and 4) it relies on few statistical assumptions. Negative attributes include: 1) it will not protect against the effects of extreme values, and 2) it is not a very representative measure of central tendency for highly skewed distributions (EPA 1994a).

The nonparametric statistical tests discussed in Chapter 8 are designed to determine whether or not the level of residual activity uniformly distributed throughout the survey unit exceeds the $DCGL_W$. Since these methods are based on ranks, the results are generally expressed in terms of the median. When the underlying measurement distribution is symmetric, the mean is equal to the median. The assumption of symmetry is less restrictive than that of normality because the normal distribution is itself symmetric. If, however, the measurement distribution is skewed to the right, the average will generally be greater than the median. In severe cases, the average may exceed the $DCGL_W$ while the median does not. For this reason, MARSSIM recommends comparing the arithmetic mean of the survey unit data to the $DCGL_W$ as a first step in the interpretation of the data (see Section 8.2.2.1).

The action level is a measurement threshold value of the parameter of interest that provides the criterion for choosing among alternative actions. MARSSIM uses the investigation level, a radionuclide-specific level of radioactivity based on the release criterion that results in additional investigation when it is exceeded, as an action level. Investigation levels are developed for both the Elevated Measurement Comparison (EMC) using scanning techniques and the statistical tests using direct measurements and samples. Section 5.5.2.6 provides information on investigation levels used in MARSSIM.

The mean concentration of residual radioactivity is the parameter of interest used for making decisions based on the final status survey. The definition of residual radioactivity depends on whether or not the contaminant appears as part of background radioactivity in the reference area. If the radionuclide is not present in background, residual radioactivity is defined as the mean

concentration in the survey unit. If the radionuclide is present in background, residual radioactivity is defined as the difference between the mean concentration in the survey unit and the mean concentration in the reference area selected to represent background. The term *1-sample case* is used when the radionuclide does not appear in background, because measurements are only made in the survey unit. The term *2-sample case* is used when the radionuclide appears in background, because measurements are made in both the survey unit and the reference area.

Figure D.3 contains a simple, hypothetical example of the 1-sample case. The upper portion of the figure shows a probability distribution of residual radionuclide concentrations in the surface soil of the survey unit. The parameter of interest is the location of the mean of this distribution, represented by the vertical dotted line and denoted by the symbol D.

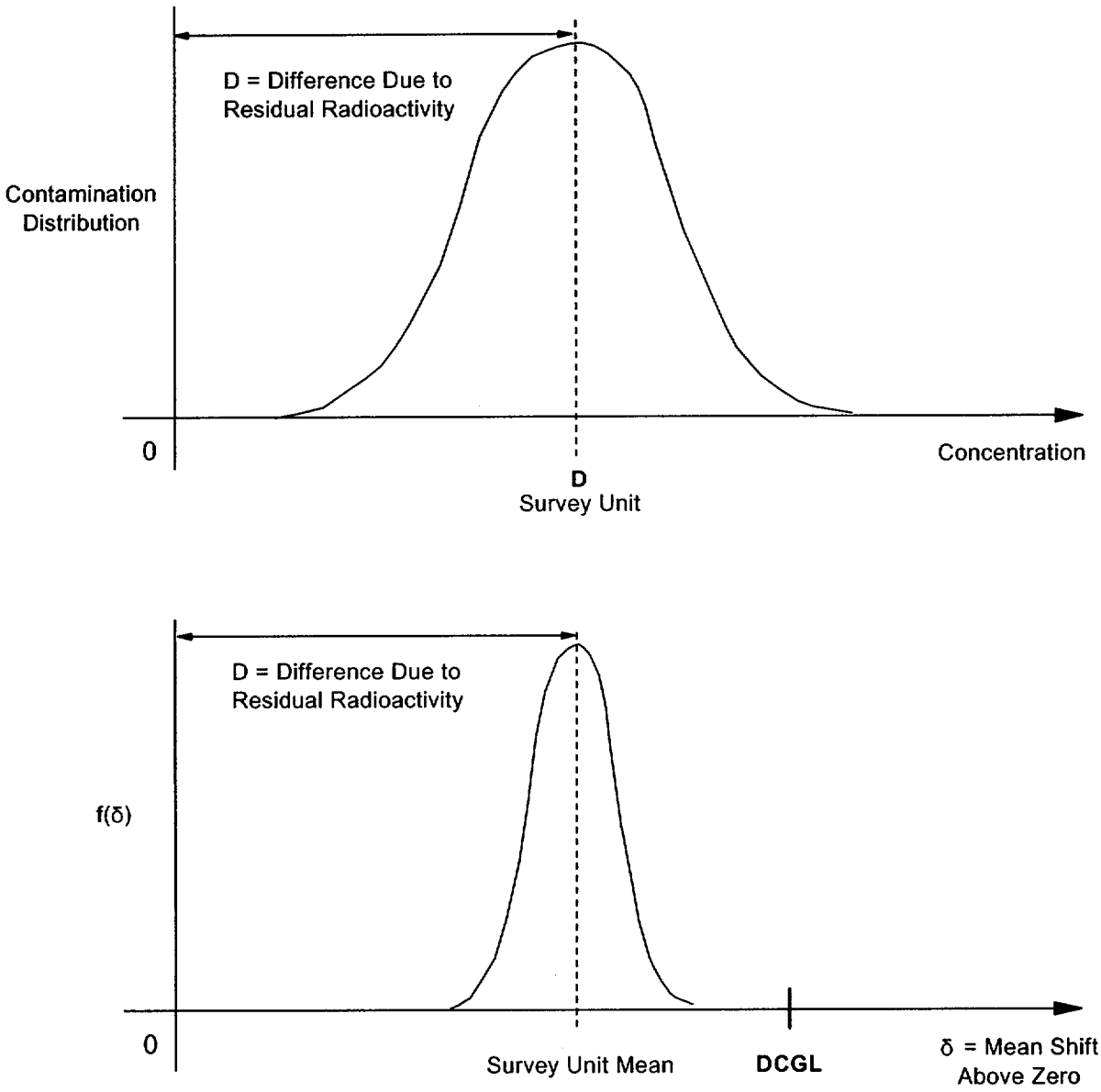
The decision rule for the 1-sample case is: "If the mean concentration in the survey unit is less than the investigation level, then the survey unit is in compliance with the release criterion." To implement the decision rule, an estimate of the mean concentration in the survey unit is required. An estimate of the mean of the survey unit distribution may be obtained by measuring radionuclide concentrations in soil at a set of n randomly selected locations in the survey unit. A point estimate for the survey unit mean is obtained by calculating the simple arithmetic average of the n measurements. Due to measurement variability, there is a distribution of possible values for the point estimate for the survey unit mean, δ. This distribution is referred to as $f(\delta)$, and is shown in the lower graph of Figure D.3. The investigation level for the Sign test used in the 1-sample case is the $DCGL_W$, shown on the horizontal axis of the graph.

If $f(\delta)$ lies far to the left (or to the right) of the $DCGL_W$, a decision of whether or not the survey unit demonstrates compliance can be easily made. However, if $f(\delta)$ overlaps the $DCGL_W$, statistical decision rules are used to assist the decision maker. Note that the width of the distribution for the estimated mean may be reduced by increasing the number of measurements. Thus, a large number of samples will reduce the probability of making decision errors.

Figure D.4 shows a simple, hypothetical example of the 2-sample case. The upper portion of the figure shows one probability distribution representing background radionuclide concentrations in the surface soil of the reference area, and another probability distribution representing radionuclide concentrations in the surface soil of the survey unit. The graph in the middle portion of the figure shows the distributions of the estimated mean concentrations in the reference area and the survey unit. In this case, the parameter of interest is the difference between the means of these two distributions, D, represented by the distance between the two vertical dotted lines.

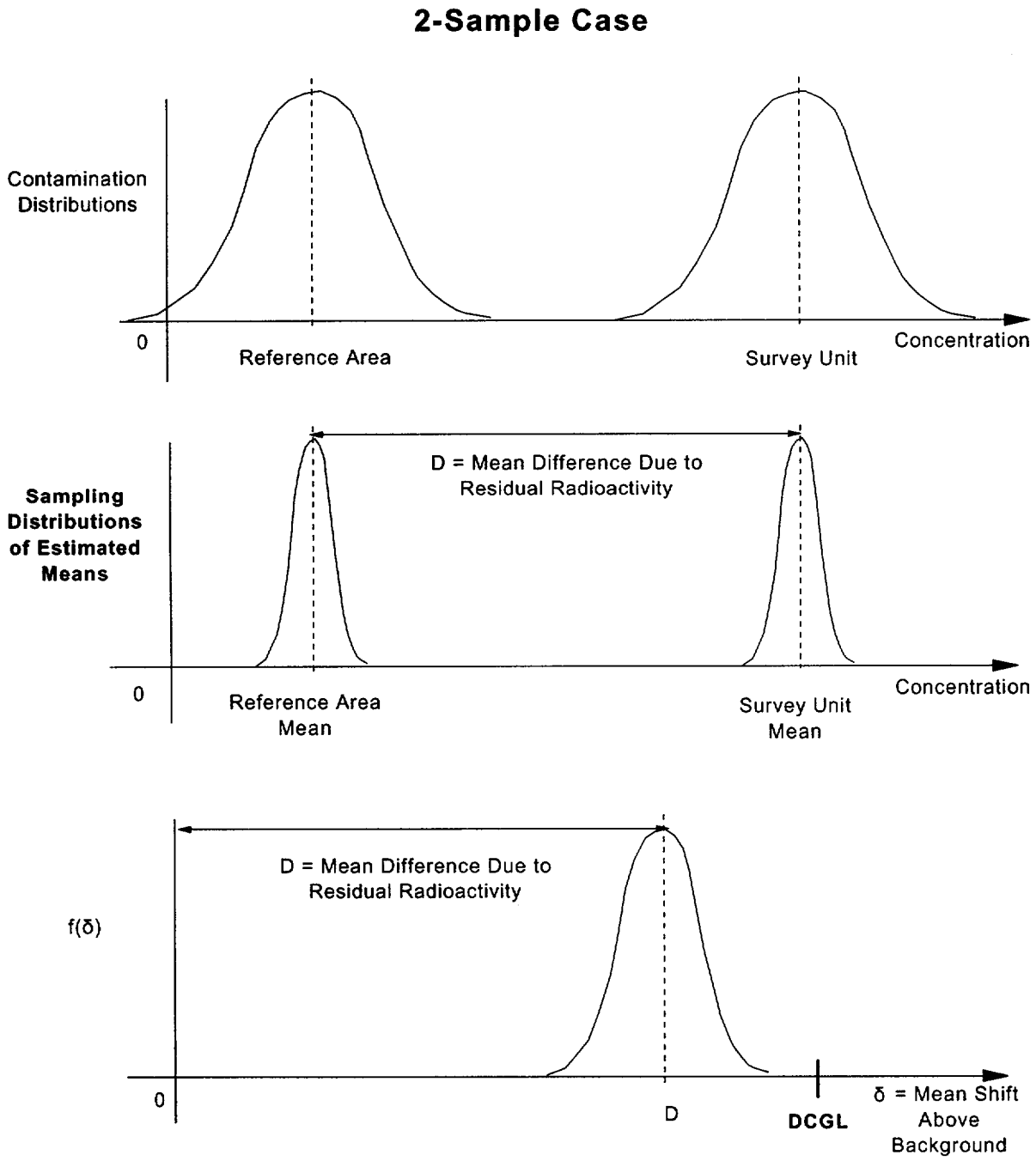
The decision rule for the 2-sample case is: "If the difference between the mean concentration in the survey unit and the mean concentration in the reference area is less than the investigation level, then the survey unit is in compliance with the release criterion." To implement the

1-Sample Case



f(δ) is the sampling distribution of the estimated survey unit mean.

Figure D.3 Example of the Parameter of Interest for the 1-Sample Case



f(δ) is the sampling distribution of the difference between the survey unit mean and the reference area mean.

Figure D.4 Example of the Parameter of Interest for the 2-Sample Case

decision rule, an estimate of the difference is required. This estimate may be obtained by measuring radionuclide concentrations at a set of "n" randomly selected locations in the survey unit and "m" randomly selected locations in the reference area. A point estimate of the survey unit mean is obtained by calculating the simple arithmetic average of the n measurements in the survey unit. A point estimate of the reference area mean is similarly calculated. A point estimate of the difference between the two means is obtained by subtracting the reference area average from the survey unit average.

The measurement distribution of this difference, $f(\delta)$, is centered at D, the true value of the difference. This distribution is shown in the lower graph of Figure D.4.

Once again, if $f(\delta)$ lies far to the left (or to the right) of the $DCGL_W$, a decision of whether or not the survey unit demonstrates compliance can be easily made. However, if $f(\delta)$ overlaps the $DCGL_W$, statistical decision rules are used to assist the decision maker.

D.6 Specify Limits on Decision Errors

Decisions based on survey results can often be reduced to a choice between "yes" or "no", such as determining whether or not a survey unit meets the release criterion. When viewed in this way, two types of incorrect decisions, or decision errors, are identified: 1) incorrectly deciding that the answer is "yes" when the true answer is "no", and 2) incorrectly deciding the answer is "no" when the true answer is "yes". The distinctions between these two types of errors are important for two reasons: 1) the consequences of making one type of error versus the other may be very different, and 2) the methods for controlling these errors are different and involve tradeoffs. For these reasons, the decision maker should specify levels for each type of decision error.

The purpose of this section is to specify the decision maker's limits on decision errors, which are used to establish performance goals for the data collection design. The goal of the planning team is to develop a survey design that reduces the chance of making a decision error.

While the possibility of a decision error can never be totally eliminated, it can be controlled. To control the possibility of making decision errors, the planning team attempts to control uncertainty in the survey results caused by sampling design error and measurement error. Sampling design error may be controlled by collecting a large number of samples. Using more precise measurement techniques or field duplicate analyses can reduce measurement error. Better sampling designs can also be developed to collect data that more accurately and efficiently represent the parameter of interest. Every survey will use a slightly different method of controlling decision errors, depending on the largest source of error and the ease of reducing those error components.

The estimate of the standard deviation for the measurements performed in a survey unit (σ_s) includes the individual measurement uncertainty as well as the spatial and temporal variations captured by the survey design. For this reason, individual measurement uncertainties are not used during the final status survey data assessment. However, individual measurement uncertainties may be useful for determining an *a priori* estimate of σ_s during survey planning. Since a larger value of σ_s results in an increased number of measurements needed to demonstrate compliance during the final status survey, the decision maker may seek to reduce measurement uncertainty through various methods (*e.g.*, different instrumentation). There are trade-offs that should be considered during survey planning. For example, the costs associated with performing additional measurements with an inexpensive measurement system may be less than the costs associated with a measurement system with better sensitivity (*i.e.*, lower measurement uncertainty, lower minimum detectable concentration). However, the more expensive measurement system with better sensitivity may reduce σ_s and the number of measurements used to demonstrate compliance to the point where it is more cost effective to use the more expensive measurement system. For surveys in the early stages of the Radiation Survey and Site Investigation Process, the measurement uncertainty and instrument sensitivity become even more important. During scoping, characterization, and remedial action support surveys, decisions about classification and remediation are made based on a limited number of measurements. When the measurement uncertainty or the instrument sensitivity values approach the value of the DCGL, it becomes more difficult to make these decisions. From an operational standpoint, when operators of a measurement system have an *a priori* understanding of the sensitivity and potential measurement uncertainties, they are able to recognize and respond to conditions that may warrant further investigation—*e.g.*, changes in background radiation levels, the presence of areas of elevated activity, measurement system failure or degradation, *etc.*

The probability of making decision errors can be controlled by adopting a scientific approach, called hypothesis testing. In this approach, the survey results are used to select between one condition of the environment (the null hypothesis, H_0) and an alternative condition (the alternative hypothesis, H_a). The null hypothesis is treated like a baseline condition that is assumed to be true in the absence of strong evidence to the contrary. Acceptance or rejection of the null hypothesis depends upon whether or not the particular survey results are consistent with the hypothesis.

A decision error occurs when the decision maker rejects the null hypothesis when it is true, or accepts the null hypothesis when it is false. These two types of decision errors are classified as Type I and Type II decision errors, and can be represented by a table as shown in Table D.1.

A Type I decision error occurs when the null hypothesis is rejected when it is true, and is sometimes referred to as a false positive error. The probability of making a Type I decision error, or the level of significance, is denoted by alpha (α). Alpha reflects the amount of evidence the decision maker would like to see before abandoning the null hypothesis, and is also referred to as the *size* of the test.

Table D.1 Example Representation of Decision Errors for a Final Status Survey

H_0: The Residual Activity in the Survey Unit Exceeds the Release Criterion			
		DECISION	
		Reject H_0 (Meets Release Criterion)	Accept H_0 (Exceeds Release Criterion)
TRUE CONDITION OF SURVEY UNIT	Meets Release Criterion	(No decision error)	Incorrectly Fail to Release Survey Unit (Type II)
	Exceeds Release Criterion	Incorrectly Release Survey Unit (Type I)	(No decision error)

A Type II decision error occurs when the null hypothesis is accepted when it is false. This is sometimes referred to as a false negative error. The probability of making a Type II decision error is denoted by beta (β). The term ($1-\beta$) is the probability of rejecting the null hypothesis when it is false, and is also referred to as the *power* of the test.

There is a relationship between α and β that is used in developing a survey design. In general, increasing α decreases β and vice versa, holding all other variables constant. Increasing the number of measurements typically results in a decrease in both α and β. The number of measurements that will produce the desired values of α and β from the statistical test can be estimated from α, β, the $DCGL_W$, and the estimated variance of the distribution of the parameter of interest.

There are five activities associated with specifying limits on decision errors:

- Determining the possible range of the parameter of interest. Establish the range by estimating the likely upper and lower bounds based on professional judgement.
- Identifying the decision errors and choosing the null hypothesis.
  a. Define both types of decision errors (Type I and Type II) and establish the true condition of the survey unit for each decision error.
  b. Specify and evaluate the potential consequences of each decision error.
  c. Establish which decision error has more severe consequences near the action level. Consequences include health, ecological, political, social, and resource risks.

d. Define the null hypothesis and the alternative hypothesis and assign the terms "Type I" and "Type II" to the appropriate decision error.

- Specifying a range of possible parameter values, a gray region, where the consequences of decision errors are relatively minor. It is necessary to specify a gray region because variability in the parameter of interest and unavoidable imprecision in the measurement system combine to produce variability in the data such that a decision may be "too close to call" when the true but unknown value of the parameter of interest is very near the action level. Additional guidance on specifying a gray region is available in *Guidance for the Data Quality Objectives Process* (EPA 1994a).
- Assigning probability limits to points above and below the gray region that reflect the probability for the occurrence of decision errors.
- Graphically representing the decision rule.

The expected outputs of this step are decision error rates based on the consequences of making an incorrect decision. Certain aspects of the site investigation process, such as the Historical Site Assessment (HSA), are not so quantitative that numerical values for decision errors can be specified. Nevertheless, a "comfort region" should be identified where the consequences of decision errors are relatively minor.

In Section D.5, the parameter of interest was defined as the difference between the survey unit mean concentration of residual radioactivity and the reference area mean concentration in the 2-sample case, or simply the survey unit mean concentration in the 1-sample case. The possible range of values for the parameter of interest is determined based on existing information (such as the Historical Site Assessment or previous surveys) and best professional judgement. The likely lower bound for $f(\delta)$ is either background or zero. For a final status survey when the residual radioactivity is expected to meet the release criterion, and a conservative upper bound might be approximately three times $DCGL_W$.

Hypothesis testing is used to determine whether or not a statement concerning the parameter of interest should be verified. The statement about the parameter of interest is called the null hypothesis. The alternative hypothesis is the opposite of what is stated in the null hypothesis. The decision maker needs to choose between two courses of action, one associated with the null hypothesis and one associated with the alternative hypothesis.

To make a decision using hypothesis testing, a test statistic is compared to a critical value. The *test statistic*[1] is a number calculated using data from the survey. The critical value of the test statistic defines a rejection region based on some assumptions about the true distribution of data in the survey unit. If the value of the test statistic falls within the rejection region, the null

[1] The test statistic is not necessarily identical to the parameter of interest, but is functionally related to it through the statistical analysis.

hypothesis is rejected. The decision rule, developed in Section D.5, is used to describe the relationship between the test statistic and the critical value.

MARSSIM considers two ways to state H_0 for a final status survey. The primary consideration in most situations will be compliance with the release criterion. This is shown as Scenario A in Figure D.5. The null hypothesis is that the survey unit exceeds the release criterion. Using this statement of H_0 means that significant evidence that the survey unit does not exceed the release criterion is required before the survey unit would be released.

In some situations, however, the primary consideration may be determining if any residual radioactivity at the site is distinguishable from background, shown as Scenario B in Figure D.6. In this manual, Scenario A is used as an illustration because it directly addresses the compliance issue and allows consideration of decision errors. More information on Scenario B can be found in the NRC draft report NUREG-1505 (NRC 1995a).

For Scenario A, the null hypothesis is that the survey unit does not meet the release criterion. A Type I decision error would result in the release of a survey unit containing residual radioactivity above the release criterion. The probability of making this error is α. Setting a high value for α would result in a higher risk that survey units that might be somewhat in excess of the release criterion would be passed as meeting the release criterion. Setting a low value for α would result in fewer survey units where the null hypothesis is rejected. However, the cost of setting a low value for α is either a higher value for β or an increased number of samples used to demonstrate compliance.

For Scenario A, the alternative hypothesis is that the survey unit does meet the release criterion. A Type II decision error would result in either unnecessary costs due to remediation of survey units that are truly below the release criterion or additional survey activities to demonstrate compliance. The probability of making a Type II error is β. Selecting a high value for β (low power) would result in a higher risk that survey units that actually meet the release criterion are subject to further investigation. Selecting a low value for β (high power) will minimize these investigations, but the tradeoff is either a higher value for α or an increased number of measurements used to demonstrate compliance. Setting acceptable values for α and β, as well as determining an appropriate gray region, is a crucial step in the DQO process.

In the MARSSIM framework, the gray region is always bounded from above by the DCGL corresponding to the release criterion. The *Lower Bound of the Gray Region* (LBGR) is selected during the DQO process along with the target values for α and β. The *width* of the gray region, equal to (DCGL - LBGR), is a parameter that is central to the nonparametric tests discussed in this manual. It is also referred to as the *shift*, Δ. The absolute size of the shift is actually of less importance than the *relative shift* Δ/σ, where σ is an estimate of the standard deviation of the measured values in the survey unit. The estimated standard deviation, σ, includes both the real spatial variability in the quantity being measured, and the precision of the chosen measurement

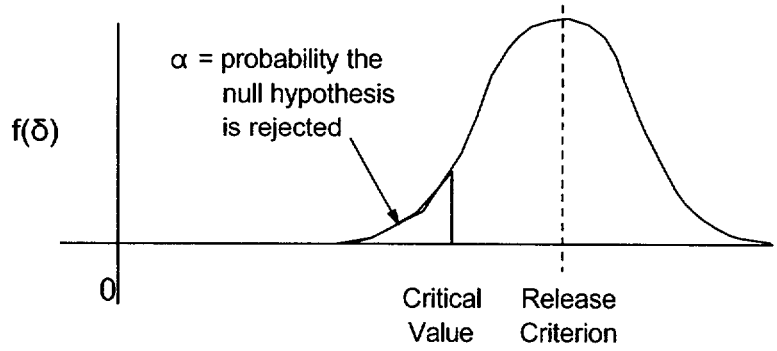
SCENARIO A

Assume as a null hypothesis that the survey unit exceeds the release criterion. This requires significant evidence that the residual radioactivity in the survey unit is less than the release criterion to reject the null hypothesis (and pass the survey unit). If the evidence is not significant at level α, the null hypothesis of a non-complying survey unit is accepted (and the survey unit fails).

HYPOTHESIS TEST

H_0: Survey unit does not meet release criterion
H_a: Survey unit does meet the release criterion

Survey unit passes if and only if the test statistic falls in the rejection region.



This test directly addresses the compliance question.

The mean shift for the survey unit must be significantly below the release criterion for the null hypothesis to be rejected.

With this test, site owners face a trade-off between additional sampling costs and unnecessary remediation costs. They may choose to increase the number of measurements in order to decrease the number of Type II decision errors (reduce the chance of remediating a clean survey unit for survey units at or near background levels.

Distinguishability from background is not directly addressed. However, sample sizes may be selected to provide adequate power at or near background levels, hence ensuring that most survey units near background would pass. Additional analyses, such as point estimates and/or confidence intervals, may be used to address this question.

A high percentage of survey units slightly below the release criterion may fail the release criterion, unless large numbers of measurements are used. This achieves a high degree of assurance that most survey units that are at or above the release criterion will not be improperly released.

Figure D.5 Possible Statement of the Null Hypothesis for the Final Status Survey Addressing the Issue of Compliance

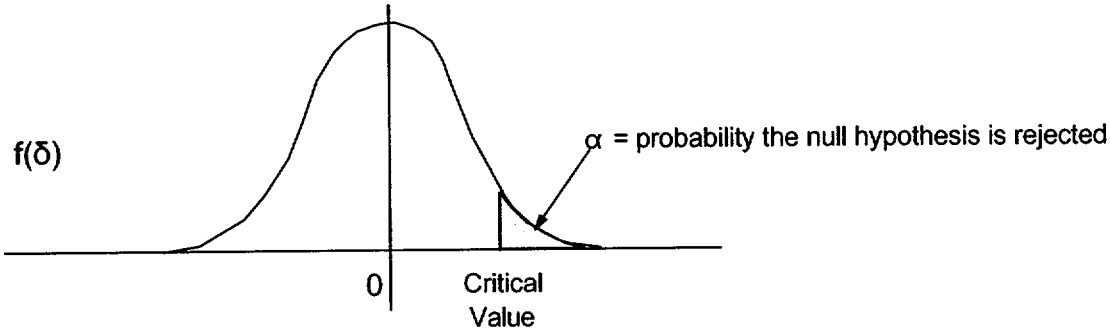
SCENARIO B

Assume as a null hypothesis that the survey unit is indistinguishable from background. This requires significant evidence that the survey unit residual radioactivity is greater than background to reject the null hypothesis (and fail the survey unit). If the evidence is not significant at level α, the null hypothesis of a clean survey unit is accepted (and the survey unit passes).

HYPOTHESIS TEST

H_0: Survey unit is indistinguishable from background
H_a: Survey unit is distinguishable from background

Survey unit passes if and only if the test statistic falls in the rejection region.



Distinguishability from background may be of primary importance to some stakeholders.

The residual radioactivity in the survey unit must be significantly above background for the null hypothesis to be rejected.

Compliance with the DCGLs is not directly addressed. However, the number of measurements may be selected to provide adequate power at or near the DCGL, hence ensuring that most survey units near the DCGL would not be improperly released. Additional analysis, based on point estimates and/or confidence intervals, is required to determine compliance if the null hypothesis is rejected by the test.

A high percentage of survey units slightly below the release criterion will fail unless large numbers of measurements are used. This is necessary to achieve a high degree of assurance that for most sites at or above the release criterion the null hypothesis will fail to be improperly released.

Figure D.6 Possible Statement of the Null Hypothesis for the Final Status Survey Addressing the Issue of Indistinguishability from Background

method. The relative shift, Δ/σ, is an expression of the resolution of the measurements in units of measurement uncertainty. Expressed in this way, it is easy to see that relative shifts of less than one standard deviation, $\Delta/\sigma < 1$, will be difficult to detect. On the other hand, relative shifts of more than three standard deviations, $\Delta/\sigma > 3$, are generally easier to detect. The number of measurements that will be required to achieve given error rates, α and β, depends almost entirely on the value of Δ/σ (see Chapter 5).

Since small values of Δ/σ result in large numbers of samples, it is important to design for $\Delta/\sigma > 1$ whenever possible. There are two obvious ways to increase Δ/σ. The first is to increase the width of the gray region by making LBGR small. Only Type II decision errors occur in the gray region. The disadvantage of making this gray region larger is that the probability of incorrectly failing to release a survey unit will increase. The target false negative rate β will be specified at lower residual radioactivity levels, i.e., a survey unit will generally have to be lower in residual radioactivity to have a high probability of being judged to meet the release criterion. The second way to increase Δ/σ is to make σ smaller. One way to make σ small is by having survey units that are relatively homogeneous in the amount of measured radioactivity. This is an important consideration in selecting survey units that have both relatively uniform levels of residual radioactivity and also have relatively uniform background radiation levels. Another way to make σ small is by using more precise measurement methods. The more precise methods might be more expensive, but this may be compensated for by the decrease in the number of required measurements. One example would be in using a radionuclide specific method rather than gross radioactivity measurements for residual radioactivity that does not appear in background. This would eliminate the variability in background from σ, and would also eliminate the need for reference area measurements.

The effect of changing the width of the gray region and/or changing the measurement variability on the estimated number of measurements (and cost) can be investigated using the DEFT (Decision Error Feasibility Trials) software developed by EPA (EPA 1995a). This program can only give approximate sample sizes and costs since it assumes that the measurement data are normally distributed, that a Student's t test will be used to evaluate the data, and that there is currently no provision for comparison to a reference area. Nevertheless, as a rough rule of thumb, the sample sizes calculated by DEFT are about 85% of those required by the one-sample nonparametric tests recommended in this manual. This rule of thumb works better for large numbers of measurements than for smaller numbers of measurements, but can be very useful for estimating the relative impact on costs of decisions made during the planning process.

Generally, the design goal should be to achieve Δ/σ values between one and three. The number of samples needed rises dramatically when Δ/σ is smaller than one. Conversely, little is usually gained by making Δ/σ larger than about three. If Δ/σ is greater than three or four, one should take advantage of the measurement precision available by making the width of the gray region smaller. It is even more important, however, that overly optimistic estimates for σ be avoided. The consequence of taking fewer samples than are needed given the actual measurement variations will be unnecessary remediations (increased Type II decision errors).

Once the preliminary estimates of Δ and σ are available, target values for α and β can be selected. The values of α and β should reflect the risks involved in making Type I and Type II decision errors, respectively.

One consideration in setting the false positive rate are the health risks associated with releasing a survey unit that might actually contain residual radioactivity in excess of the $DCGL_W$. If a survey unit did exceed the $DCGL_W$, the first question that arises is "How much above the $DCGL_W$ is the residual radioactivity likely to be?" The DEFT software can be used to evaluate this.

For example, if the $DCGL_W$ is 100 Bq/kg (2.7 pCi/g), the LBGR is 50 Bq/kg (1.4 pCi/g), σ is 50 Bq/kg (1.4 pCi/g), $\alpha = 0.10$ and $\beta = 0.05$, the DEFT calculations show that while a survey unit with residual radioactivity equal to the $DCGL_W$ has a 10% chance of being released, a survey unit at a level of 115 Bq/kg (3.1 pCi/g) has less than a 5% chance of being released, a survey unit at a level of 165 Bq/kg (4.5 pCi/g) has virtually no chance of being released. However, a survey unit with a residual radioactivity level of 65 Bq/kg (1.8 pCi/g) will have about an 80% chance of being released and a survey unit with a residual radioactivity level of 80 Bq/kg (2.2 pCi/g) will only have about a 40% chance of being released. Therefore, it is important to examine the probability of deciding that the survey unit does not meet the release criterion over the entire range of possible residual radioactivity values, and not only at the boundaries of the gray region. Of course, the gray region can be made narrower, but at the cost of additional sampling. Since the equations governing the process are not linear, small changes can lead to substantial changes in survey costs.

As stated earlier, the values of α and β that are selected in the DQO process should reflect the risk involved in making a decision error. In setting values for α, the following are important considerations:

- In radiation protection practice, public health risk is modeled as a linear function of dose (BEIR 1990). Therefore a 10% change in dose, say from 15 to 16.5, results in a 10% change in risk. This situation is quite different from one in which there is a threshold. In the latter case, the risk associated with a decision error can be quite high, and low values of α should be selected. When the risk is linear, much higher values of α at the release criterion might be considered adequately protective when the survey design results in smaller decision error rates at doses or risks greater than the release criterion. False positives will tend to be balanced by false negatives across sites and survey units, resulting in approximately equal human health risks.
- The DCGL itself is not free of error. The dose or risk cannot be measured directly, and many assumptions are made in converting doses or risks to derived concentrations. To be adequately protective of public health, these models are generally designed to over predict the dose or risk. Unfortunately, it is difficult to quantify this. Nonetheless, it is probably safe to say that most models have uncertainty sufficiently large such that the true dose or risk delivered by residual radioactivity at the DCGL is very likely to be lower than the

release criterion. This is an additional consideration for setting the value of α, that could support the use of larger values in some situations. In this case, one would prospectively address, as part of the DQO process, the magnitude, significance, and potential consequences of decision errors at values above the release criterion. The assumptions made in any model used to predict DCGLs for a site should be examined carefully to determine if the use of site specific parameters results in large changes in the DCGLs, or whether a site-specific model should be developed rather than designing a survey around DCGLs that may be too conservative.

- The risk of making the second type of decision error, β, is the risk of requiring additional remediation when a survey unit already meets the release criterion. Unlike the health risk, the cost associated with this type of error may be highly non-linear. The costs will depend on whether the survey unit has already had remediation work performed on it, and the type of residual radioactivity present. There may be a threshold below which the remediation cost rises very rapidly. If so, a low value for β is appropriate at that threshold value. This is primarily an issue for survey units that have a substantial likelihood of falling at or above the gray region for residual radioactivity. For survey units that are very lightly contaminated, or have been so thoroughly remediated that any residual radioactivity is expected to be far below the DCGL, larger values of β may be appropriate especially if final status survey sampling costs are a concern. Again, it is important to examine the probability of deciding that the survey unit does not meet the release criterion over the entire range of possible residual radioactivity values, below as well as above the gray region.
- Lower decision error rates may be possible if alternative sampling and analysis techniques can be used that result in higher precision. The same might be achieved with moderate increases in sample sizes. These alternatives should be explored before accepting higher design error rates. However, in some circumstances, such as high background variations, lack of a radionuclide specific technique, and/or radionuclides that are very difficult and expensive to quantify, error rates that are lower than the uncertainties in the dose or risk estimates may be neither cost effective nor necessary for adequate radiation protection.

None of the above discussion is meant to suggest that under any circumstances a less than rigorous, thorough, and professional approach to final status surveys would be satisfactory. The decisions made and the rationale for making these decisions should be thoroughly documented.

For Class 1 Survey Units, the number of samples may be driven more by the need to detect small areas of elevated activity than by the requirements of the statistical tests. This in turn will depend primarily on the sensitivity of available scanning instrumentation, the size of the area of elevated activity, and the dose or risk model. A given concentration of residual radioactivity spread over a smaller area will, in general, result in a smaller dose or risk. Thus, the $DCGL_{EMC}$ used for the elevated measurement comparison is usually larger than the $DCGL_W$ used for the statistical test. In some cases, especially radionuclides that deliver dose or risk primarily via internal pathways,

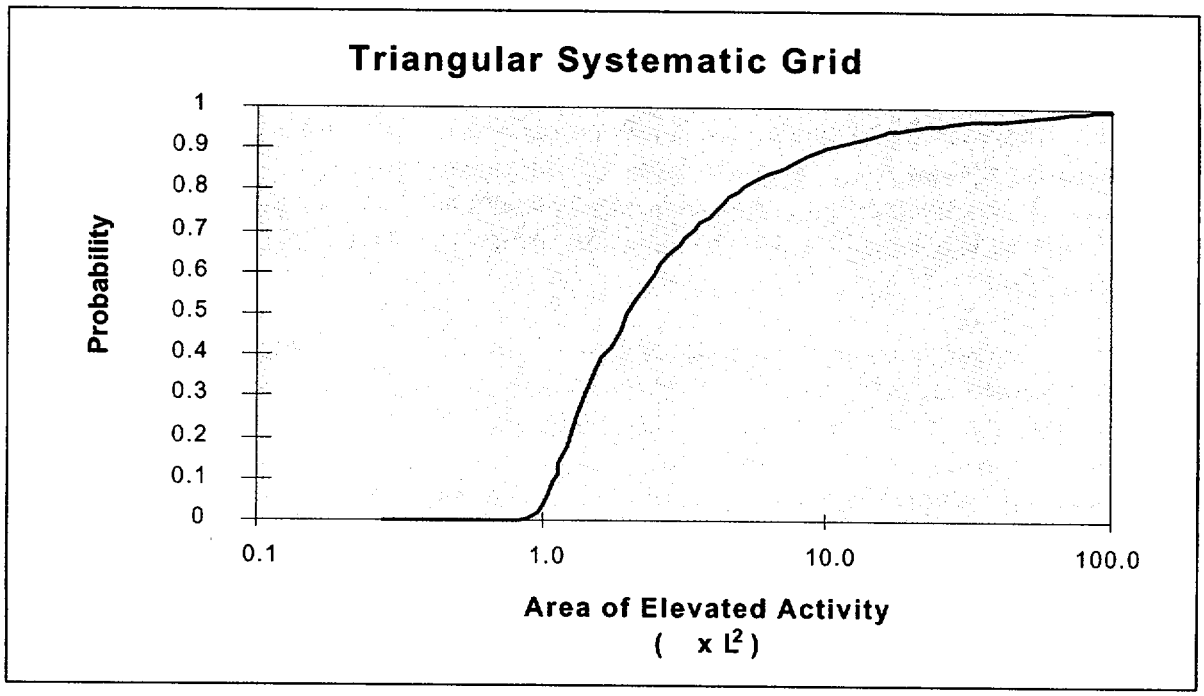
dose or risk is approximately proportional to inventory, and so the difference in the DCGLs is approximately proportional to the areas.

However, this may not be the case for radionuclides that deliver a significant portion of the dose or risk via external exposure. The exact relationship between the $DCGL_{EMC}$ and the $DCGL_W$ is a complicated function of the dose or risk modeling pathways, but area factors to relate the two DCGLs can be tabulated for most radionuclides (see Chapter 5), and site-specific area factors can also be developed.

For many radionuclides, scanning instrumentation is readily available that is sensitive enough to detect residual radioactivity concentrations at the $DCGL_{EMC}$ derived for the sampling grid of direct measurements used in the statistical tests. Where instrumentation of sufficient sensitivity (MDC, see Chapter 6) is not available, the number of samples in the survey unit can be increased until the area between sampling points is small enough (and the resulting area factor is large enough) that $DCGL_{EMC}$ can be detected by scanning. The details of this process are discussed in Chapter 5. For some radionuclides (*e.g.*, ^3H) the scanning sensitivity is so low that this process would never terminate—*i.e.*, the number of samples required could increase without limit. Thus, an important part of the DQO process is to determine the smallest size of an area of elevated activity that it is important to detect, A_{min} , and an acceptable level of risk , R_A , that it may go undetected. The probability of sampling a circular area of size A with either a square or triangular sampling pattern is shown in Figure D.7. The ELIPGRID-PC (Davidson 1995) computer code can also be used to calculate these probabilities.

In this part of the DQO process, the concern is less with areas of elevated activity that are found than with providing adequate assurance that negative scanning results truly demonstrate the absence of such areas. In selecting acceptable values for A_{min} and R_A, maximum use of information from the HSA and all surveys prior to the final status surveys should be used to determine what sort of areas of elevated activity could possibly exist, their potential size and shape, and how likely they are to exist. When the detection limit of the scanning technique is very large relative to the $DCGL_{EMC}$, the number of measurements estimated to demonstrate compliance using the statistical tests may become unreasonably large. In this situation an evaluation of the survey objectives and considerations be performed. These considerations may include the survey design and measurement methodology, exposure pathway modeling assumptions and parameter values used to determine the DCGLs, Historical Site Assessment conclusions concerning source terms and radionuclide distributions, and the results of scoping and characterization surveys. In most cases the results of this evaluation is not expected to justify an unreasonably large number of measurements.

A convenient method for visualizing the decision rule is to graph the probability of deciding that the survey unit does not meet the release criterion, *i.e.*, that the null hypothesis of Scenario A is accepted. An example of such a chart is shown in Figure D.8.



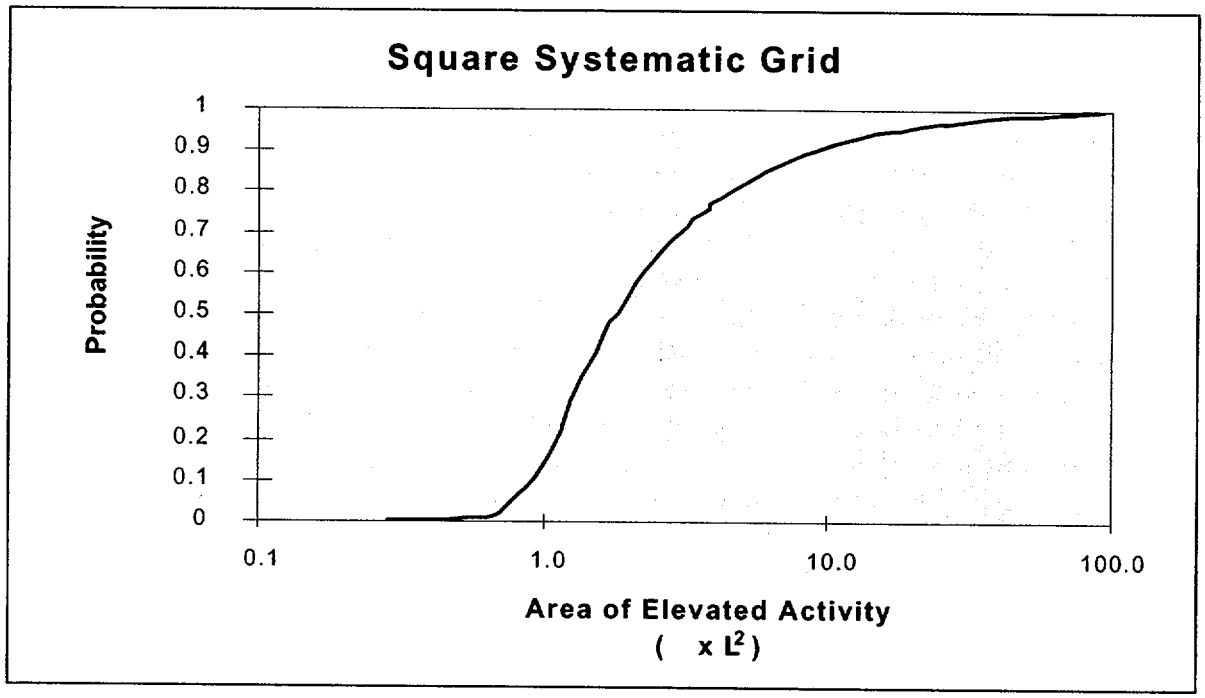


Figure D.7 Geometric Probability of Sampling at Least One Point of an Area of Elevated Activity as a Function of Sample Density with Either a Square or Triangular Sampling Pattern

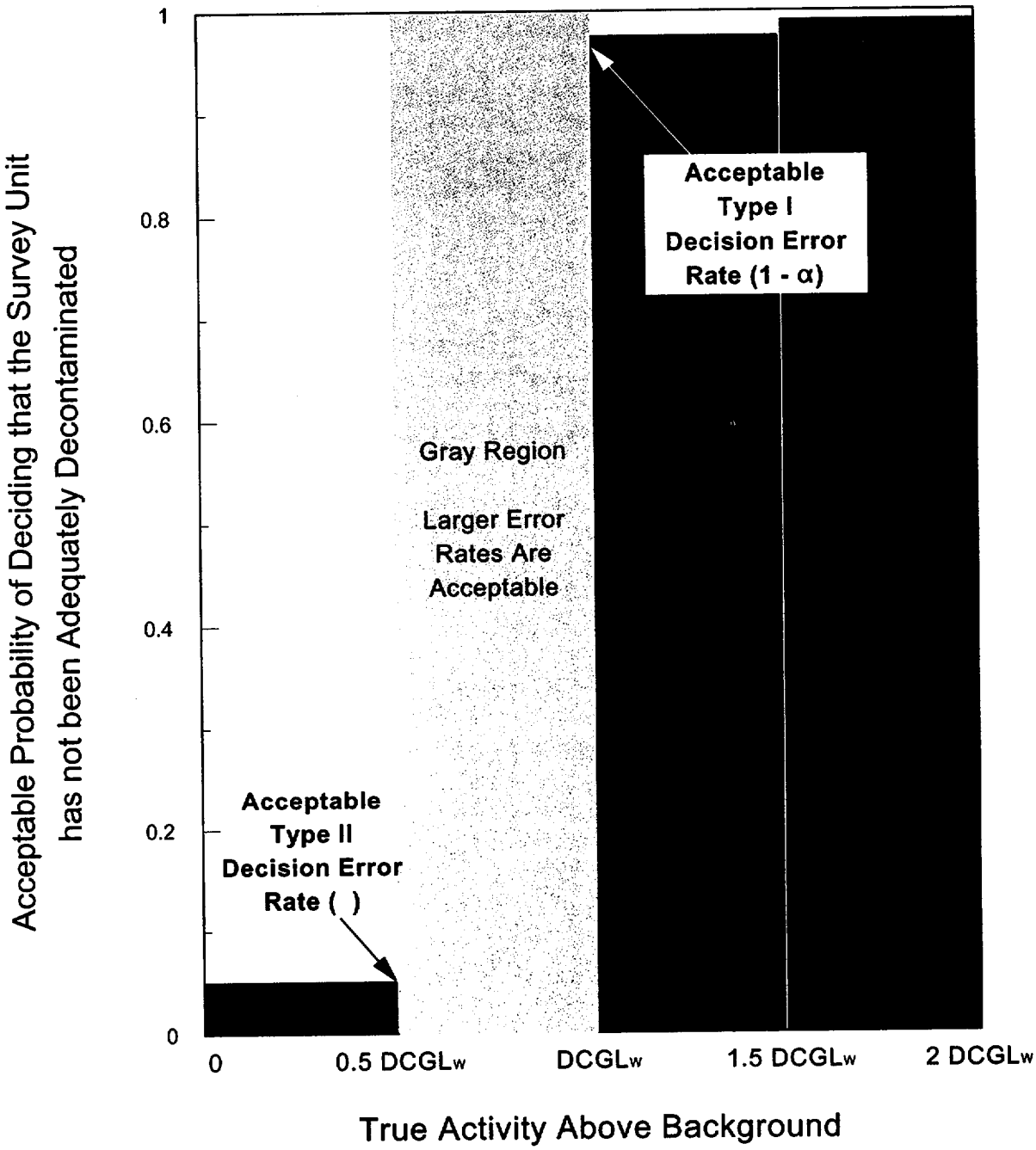


Figure D.8 Example of a Power Chart Illustrating the Decision Rule for the Final Status Survey

In this example α is 0.025 and β is 0.05, providing an expected power (1-β) of 0.95 for the test. A second method for presenting the information is shown in Figure D.9. This figure shows the probability of making a decision error for possible values of the parameter of interest, and is referred to as an error chart. In both examples a gray region, where the consequences of decision errors are deemed to be relatively minor, is shown. These charts are used in the final step of the DQO Process, combined with the outputs from the previous steps, to produce an efficient and cost-effective survey design. It is clear that setting acceptable values for α and β, as well as determining an appropriate gray region, is a crucial step in the DQO Process. Instructions for creating a prospective power curve, which can also be used to visualize the decision rule, are provided in Appendix I.

After the survey design is implemented, the expected values of α and β determined in this step are compared to the actual significance level and power of the statistical test based on the measurement results during the assessment phase of the Data Life Cycle. This comparison is used to verify that the objectives of the survey have been achieved.

EPA QA/G-9 (EPA 1996a) discusses considerations for selecting a particular null hypothesis. Because of the basic hypothesis testing philosophy, the null hypothesis is generally specified in terms of the *status quo* (*e.g.*, no change or action will take place if the null hypothesis is not rejected). Also, since the classical hypothesis testing approach exercises direct control over the Type I (false positive) error rate, this rate is generally associated with the error of most concern. In the case of the null hypothesis in which the residual radioactivity in the survey unit exceeds the release criterion, a Type I decision error would conclude that the residual activity was less than the release criterion when in fact it was above the release criterion. One difficulty, therefore, may be obtaining a consensus on which error should be of most concern (i.e., releasing a site where the residual activity exceeds the release criterion or failing to release a site where the residual activity is less than the release criterion). It is likely that the regulatory agency's public health-based protection viewpoint will differ from the viewpoint of the regulated party. The ideal approach is not only to define the null hypothesis in such a way that the Type I decision error protects human health and the environment but also in a way that encourages quality (high precision and accuracy) and minimizes expenditure of resources in situations where decisions are relatively "easy" (*e.g.*, all observations are far below the threshold level of interest or DCGL).

To avoid excessive expense in performing measurements, compromises are sometimes necessary. For example, suppose that a significance level (α) of 0.05 is to be used. However, the affordable sample size may be expected to yield a test with power (β) of only 0.40 at some specified parameter value chosen to have practical significance. One possible compromise may be to relax the Type I decision error rate (α) and use a value of 0.10, 0.15, or even 0.20. By relaxing the Type I decision error rate, a higher power (*i.e.*, a lower Type II decision error rate) can be achieved. An argument can be made that survey designs should be developed and number of measurements determined in such a way that both the Type I (α) and Type II (β) decision error rates are treated simultaneously and in a balanced manner (i.e., $\alpha = \beta = 0.15$). This approach of

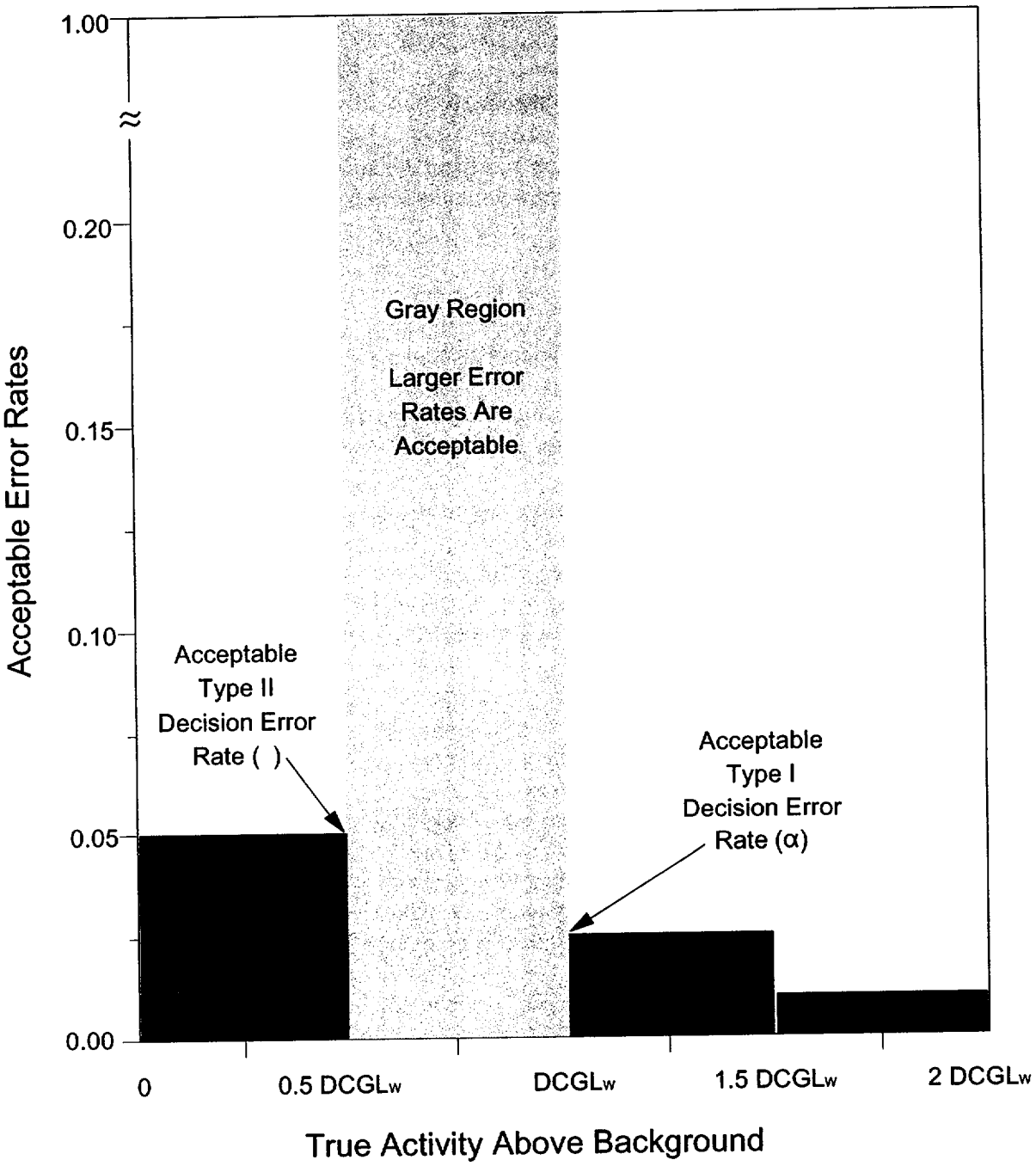


Figure D.9 Example of an Error Chart Illustrating the Decision Rule for the Final Status Survey

treating the Type I and Type II decision error rates simultaneously is taken by the DQO Process. It is recommended that several different values for α and β be investigated before specific values are selected.

D.7 Optimize the Design for Collecting Data

This step is designed to produce the most resource-effective survey design that is expected to meet the DQOs. It may be necessary to work through this step more than once after revisiting previous steps in the DQO Process.

There are six activities included in this step:

- Reviewing the DQO outputs and existing environmental data to ensure they are internally consistent.
- Developing general data collection design alternatives. Chapter 5 describes random and systematic sampling designs recommended for final status surveys based on survey unit classification.
- Formulating the mathematical expressions needed to solve the design problem for each data collection design alternative.
- Selecting the optimal design that satisfies the DQOs for each data collection design alternative. If the recommended design will not meet the limits on decision errors within the budget or other constraints, then the planning team will need to relax one or more constraints. Examples include:
  a. increasing the budget for sampling and analysis
  b. using exposure pathway modeling to develop site-specific DCGLs
  c. increasing the decision error rates, not forgetting to consider the risks associated with making an incorrect decision
  d. increasing the width of the gray region by decreasing the LBGR
  e. relaxing other project constraints—*e.g.*, schedule
  f. changing the boundaries—it may be possible to reduce measurement costs by changing or eliminating survey units that will require different decisions
  g. evaluating alternative measurement techniques with lower detection limits or lower survey costs
  h. considering the use of passive controls when releasing the survey unit rather than unrestricted release
- Selecting the most resource-effective survey design that satisfies all of the DQOs. Generally, the survey designs described in Chapter 5 will be acceptable for demonstrating compliance. Atypical sites (*e.g.*, mixed-waste sites) may require the planning team to consider alternative survey designs on a site-specific basis.

- Documenting the operational details and theoretical assumptions of the selected design in the QAPP, the field sampling plan, the sampling and analysis plan, or the decommissioning plan. All of the decisions that will be made based on the data collected during the survey should be specified along with the alternative actions that may be adopted based on the survey results.

Chapters 4 and 5 present a framework for a final status survey design. When this framework is combined with the site-specific DQOs developed using the guidance in this section, the survey design should be acceptable for most sites. The key inputs to Chapters 4 and 5 are:

- investigation levels and DCGLs for each radionuclide of interest
- acceptable measurement techniques for scanning, sampling, and direct measurements, including detection limits and estimated survey costs
- identification and classification of survey units
- an estimate of the variability in the distribution of residual radioactivity for each survey unit, and in the reference area if necessary
- the decision maker's acceptable *a priori* values for decision error rates (α and β)

APPENDIX E

THE ASSESSMENT PHASE OF THE DATA LIFE CYCLE

The assessment phase of the Data Life Cycle includes verification and validation of the survey data and assessment of quality of the data. Data verification is used to ensure that the requirements stated in the planning documents are implemented as prescribed. Data validation is used to ensure that the results of the data collection activities support the objectives of the survey as documented in the Quality Assurance Project Plan (QAPP), or permit a determination that these objectives should be modified. Data Quality Assessment (DQA) is the scientific and statistical evaluation of data to determine if the data are of the right type, quality, and quantity to support their intended use (EPA 1996a). DQA helps complete the Data Life Cycle by providing the assessment needed to determine that the planning objectives are achieved. Figure E.1 illustrates where data verification, data validation and DQA fit into the Assessment Phase of the Data Life Cycle.

There are five steps in the DQA Process:

- Review the Data Quality Objectives (DQOs) and Survey Design
- Conduct a Preliminary Data Review
- Select the Statistical Test
- Verify the Assumptions of the Statistical Test
- Draw Conclusions from the Data

These five steps are presented in a linear sequence, but the DQA process is applied in an iterative fashion much like the DQO process. The strength of the DQA process is that it is designed to promote an understanding of how well the data will meet their intended use by progressing in a logical and efficient manner.

E.1 Review DQOs and Survey Design

The DQA process begins by reviewing the key outputs from the Planning phase of the Data Life Cycle that are recorded in the planning documents (*e.g.*, the QAPP). The DQOs provide the context for understanding the purpose of the data collection effort. They also establish qualitative and quantitative criteria for assessing the quality of the data set for the intended use. The survey design (documented in the QAPP) provides important information about how to interpret the data.

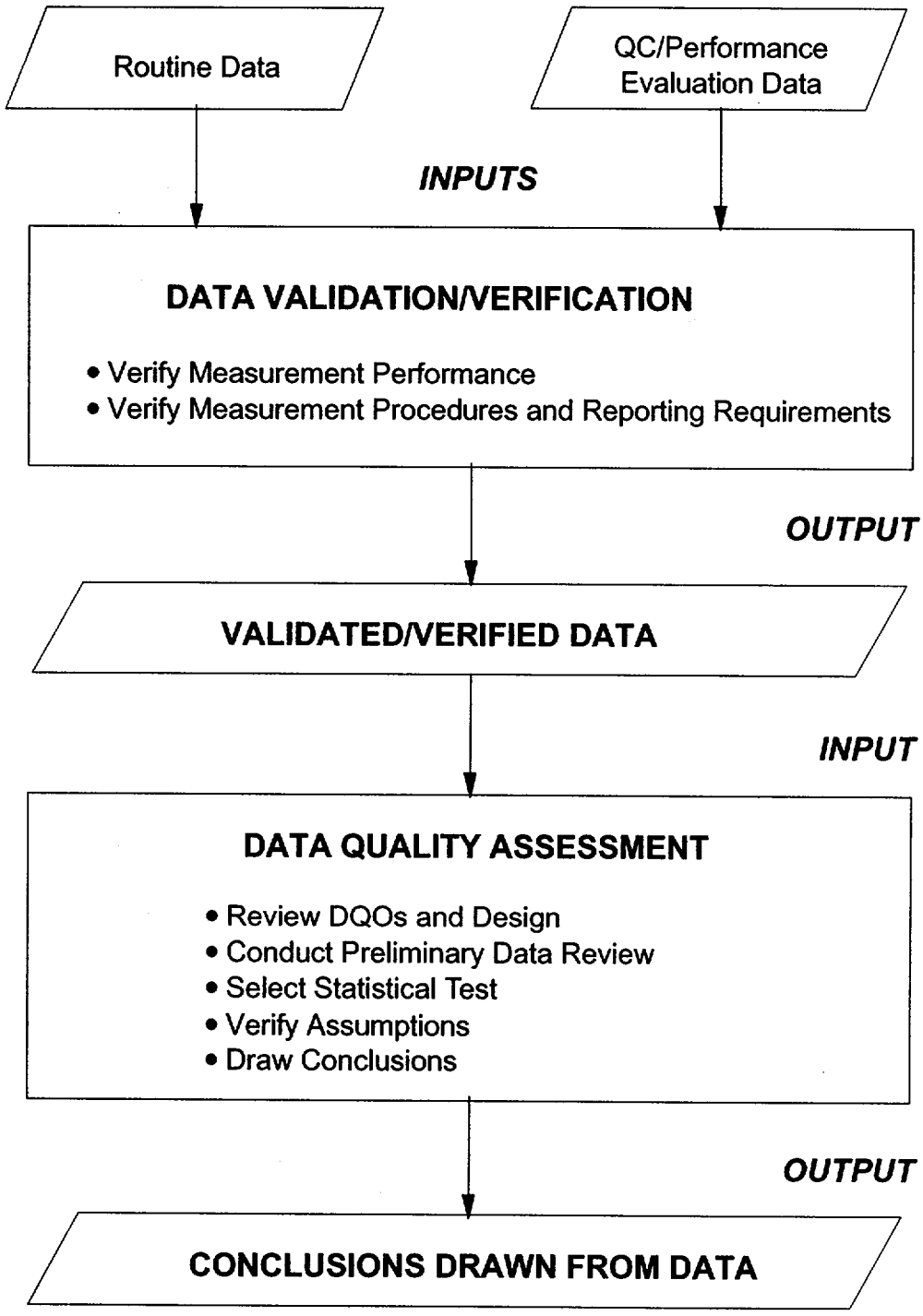


Figure E.1 The Assessment Phase of the Data Life Cycle (EPA 1996a)

There are three activities associated with this step in the DQA process:

- Translating the data user's objectives into a statement of the hypotheses to be tested using environmental data. These objectives should be documented as part of the DQO Process, and this activity is reduced to translating these objectives into the statement of hypotheses. If DQOs have not been developed, which may be the case for historical data, review Appendix D for assistance in developing these objectives.

- Translating the objectives into limits on the probability of committing Type I or Type II decision errors. Appendix D, Section D.6 provides guidance on specifying limits on decision errors as part of the DQO process.

- Reviewing the survey design and noting any special features or potential problems. The goal of this activity is to familiarize the analyst with the main features of the survey design used to generate the environmental data. Review the survey design documentation (*e.g.*, the QAPP) with the data user's objectives in mind. Look for design features that support or contradict these objectives.

For the final status survey, this step would consist of a review of the DQOs developed using Appendix D and the QAPP developed in Chapter 9.

E.2 Conduct a Preliminary Data Review

In this step of the DQA process, the analyst conducts a preliminary evaluation of the data set, calculating some basic statistical quantities and looking at the data through graphical representations. By reviewing the data both numerically and graphically, the analyst can learn the "structure" of the data and thereby identify appropriate approaches and limitations for their use.

This step includes three activities:

- reviewing quality assurance reports
- calculating statistical quantities (*e.g.*, relative standing, central tendency, dispersion, shape, and association)
- graphing the data (*e.g.*, histograms, scatter plots, confidence intervals, ranked data plots, quantile plots, stem-and-leaf diagrams, spatial or temporal plots)

Chapter 8 discusses the application of these activities to a final status survey.

E.3 Select the Statistical Test

The statistical tests presented in Chapter 8 are applicable for most sites contaminated with radioactive material. Chapter 2 discusses the rationale for selecting the statistical methods recommended for the final status survey in more detail. Additional guidance on selecting alternate statistical methods can be found in Section 2.6 and in EPA's DQA guidance document (EPA 1995).

E.4 Verify the Assumptions of the Statistical Test

In this step, the analyst assesses the validity of the statistical test by examining the underlying assumptions in light of the environmental data. The key questions to be resolved are: "Do the data support the underlying assumptions of the test?", and: "Do the data suggest that modifications to the statistical analysis are warranted?"

The underlying assumptions for the statistical tests are discussed in Section 2.5. Graphical representations of the data, such as those described in Section 8.2 and Appendix I, can provide important qualitative information about the validity of the assumptions. Documentation of this step is always important, especially when professional judgement plays a role in accepting the results of the analysis.

There are three activities included in this step:

- Determining the approach for verifying assumptions. For this activity, determine how the assumptions of the hypothesis test will be verified, including assumptions about distributional form, independence, dispersion, type, and quantity of data. Chapter 8 discusses methods for verifying assumptions for the final status survey statistical test during the preliminary data review.

- Performing tests of the assumptions. Perform the calculations selected in the previous activity for the statistical tests. Guidance on performing the tests recommended for the final status survey are included in Chapter 8.

- Determining corrective actions (if any). Sometimes the assumptions underlying the hypothesis test will not be satisfied and some type of corrective action should be performed before proceeding. In some cases, the data for verifying some key assumption may not be available and existing data may not support the assumption. In this situation, it may be necessary to collect new data, transform the data to correct a problem with the distributional assumptions, or select an alternate hypothesis test. Section 9.3 discusses potential corrective actions.

E.5 Draw Conclusions from the Data

The final step of the DQA process is performing the statistical test and drawing conclusions that address the data user's objectives. The procedure for implementing the statistical test is included in Chapter 8.

There are three activities associated with this final step:

- Performing the calculations for the statistical hypothesis test (see Chapter 8).
- Evaluating the statistical test results and drawing the study conclusions. The results of the statistical test will be either accept the null hypothesis, or reject the null hypothesis.
- Evaluating the performance of the survey design if the design is to be used again. If the survey design is to be used again, either in a later phase of the current study or in a similar study, the analyst will be interested in evaluating the overall performance of the design. To evaluate the survey design, the analyst performs a statistical power analysis that describes the estimated power of the test over the full range of possible parameter values. This helps the analyst evaluate the adequacy of the sampling design when the true parameter value lies in the vicinity of the action level (which may not have been the outcome of the current study). It is recommended that a statistician be consulted when evaluating the performance of a survey design for future use.

APPENDIX F

THE RELATIONSHIP BETWEEN THE RADIATION SURVEY AND SITE INVESTIGATION PROCESS, THE CERCLA REMEDIAL OR REMOVAL PROCESS, AND THE RCRA CORRECTIVE ACTION PROCESS

This appendix presents a discussion of the relationship between the Radiation Survey and Site Investigation Process, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Remedial or Removal Process, and the Resource Conservation and Recovery Act (RCRA) Corrective Action Process. Each of these processes has been designed to incorporate survey planning using the Data Quality Objectives (DQO) Process and data interpretation using Data Quality Assessment (DQA) using a series of surveys to accomplish the project objectives. At this basic level, MARSSIM is consistent with the other processes.

Figure F.1 illustrates the relationship between the major steps in each of these processes. As shown in Figure F.1, the scope of MARSSIM (Section 1.1) results in steps in the CERCLA Remedial or Removal Process and the RCRA Process that are not directly addressed by MARSSIM (*e.g.*, Feasibility Study or Corrective Measure Study). MARSSIM's focus on the demonstration of compliance for sites with residual radioactivity using a final status survey integrates with the remedial design/remedial action (RD/RA) step of the CERCLA Remedial Process described in Sec. 300.435(b)(1) of Part 40 of the Code of Federal Regulations. However, MARSSIM's focus is not directly addressed by the major steps of the CERCLA Removal Process or the RCRA Corrective Action Process.

Much of the guidance presented in MARSSIM for designing surveys and assessing the survey results is taken directly from the corresponding CERCLA or RCRA guidance. MARSSIM users familiar with the Superfund Preliminary Assessment guidance (EPA 1991f) will recognize the guidance provided on performing the Historical Site Assessment (Chapter 3) for identifying potentially contaminated soil, water, or sediment. In addition, MARSSIM provides guidance for identifying potentially contaminated structures which is not covered in the original CERCLA guidance. The survey designs and statistical tests for relatively uniform distributions of residual radioactivity discussed in MARSSIM are also discussed in CERCLA guidance (EPA 1989a, EPA 1994b). However, MARSSIM includes scanning for radioactive materials which isn't discussed in the more general CERCLA guidance that doesn't specifically address radionuclides. MARSSIM is not designed to replace or conflict with existing CERCLA or RCRA guidance, it is designed to provide supplemental guidance for specific applications of the CERCLA Remedial or Removal Process or the RCRA Corrective Action Process.

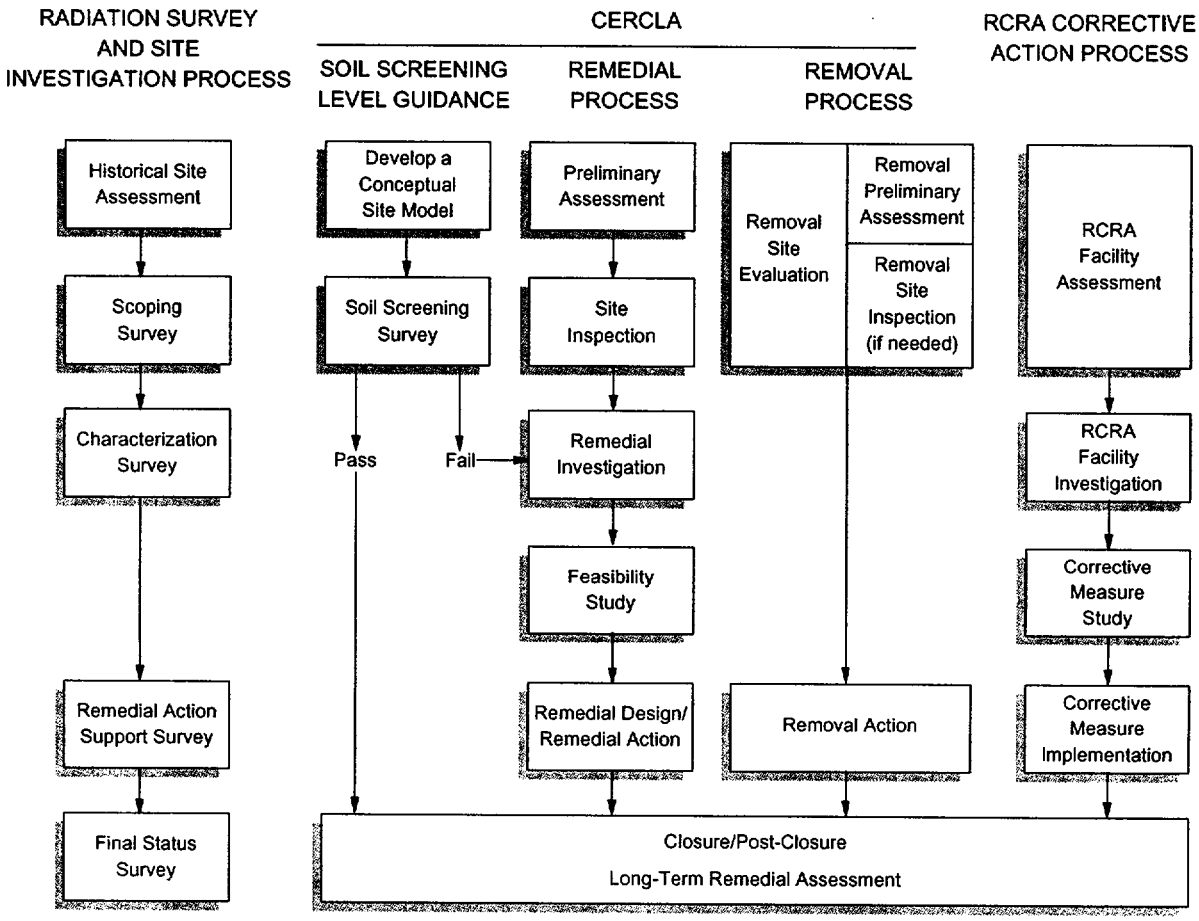


Figure F.1 Comparison of the Radiation Survey and Site Investigation Process with the CERCLA Superfund Process and the RCRA Corrective Action Process

Table F.1 lists the major steps in MARSSIM and other CERCLA and RCRA processes and describes the objectives of each step. This table provides a direct comparison of these processes, and it shows the correlation between the processes. This correlation is the result of carefully integrating CERCLA and RCRA guidance with guidance from other agencies participating in the development of MARSSIM to produce a multi-agency consensus document.

The first step in the CERCLA Remedial Process is the preliminary assessment to obtain existing information about the site and determine if there is a threat to human health and the environment. The next step is the site inspection which includes risk prioritization using the Hazard Ranking System—sites with a score above a certain level are put on the National Priorities List (NPL). Following the site assessment, the remedial investigation (RI) is performed to characterize the

extent and type of release, and to evaluate the risk to human health and the environment. A Sampling and Analysis Plan is constructed as part of the remedial investigation which consists of a Quality Assurance Project Plan, a Field Sampling Plan, a Health and Safety Plan, and a Community Relations Plan. The site feasibility study (FS) is the next step in the CERCLA Remedial Process (although the RI and FS are intended to be done concurrently) which involves an evaluation of alternative remedial actions. For sites listed on the NPL the next action would be to obtain a Record of Decision (ROD) which provides the remedy selected for the site. The remedial design/remedial action (RD/RA), which includes the development of the selected remedy and its implementation, follows development of the ROD. After the RD/RA activities there is a period of operation and maintenance when the site is given a long term remedial assessment followed by closure/post-closure of the site (or removal from the NPL). A removal action may occur at any stage of the CERCLA Remedial Process.

The CERCLA Removal Process is similar to the Remedial Process for the first few steps. 40 CFR 300.400 (NCP Subpart E—Hazardous Substance Response) establishes methods and criteria for determining the extent of response when there is a release into the environment of a hazardous substance or any pollutant or contaminant that may present an imminent and substantial danger to the public health or welfare of the United States. The first step in the Removal Process is a removal site evaluation which includes a removal preliminary assessment and, if warranted, a removal site inspection. A removal preliminary assessment may be based on available information and should include an evaluation of the factors necessary to make the determination of whether a removal is necessary. A removal site inspection is performed, if warranted, in a similar manner as in the CERCLA Remedial Process. If environmental samples are to be collected, a sampling and analysis plan should be developed which consists of a field sampling plan and a quality assurance project plan. Post-removal site controls are those activities necessary to sustain the effectiveness and integrity of the removal action. In the case of all CERCLA removal actions taken pursuant to 300.415, a designated spokesperson will inform the community of actions taken, respond to inquiries, and provide information concerning the release—this may include a formal community relations plan specifying the community relations activities expected during the removal response.

Comparisons have been made between the CERCLA Remedial Process and CERCLA Removal Process (EPA, 1993c). Table F.2 presents the data elements that are common to both programs and those that are generally common to one program rather than the other. Table F.3 shows the emphasis placed on sampling for remedial site assessment versus removal site assessment.

Another guidance document that can be compared to MARSSIM is the Soil Screening Guidance (EPA 1996b, EPA 1996c), which facilitates removing sites from consideration early in the CERCLA Process. Although not written to specifically address radioactive contaminants, the Soil Screening Guidance leads the user from the initial site conceptualization and planning stages through data collection and evaluation to the final testing step. MARSSIM also leads the user through similar planning, evaluation, and testing stages, but the guidance focuses on the final compliance demonstration step.

The Soil Screening Guidance provides a way to calculate risk-based, site-specific, soil screening levels (SSLs) for contaminants in soil. SSLs can be used as preliminary remediation goals (PRGs) if the conditions found at a specific site are similar to the conditions assumed in calculating the SSLs.

Both the Soil Screening Guidance and MARSSIM provide examples of acceptable sampling and analysis plans (SAP) for site contaminants. The Soil Screening Guidance recommended default survey design for surface soils is very specific—recommendations for the grid size for sampling, the number of soil samples collected from each subarea and composited, and data analysis and interpretation techniques are described in detail. MARSSIM provides guidance that is consistent and compatible with the Soil Screening Guidance with respect to the approaches, framework, tools, and overall objectives.

SSLs calculated using the CERCLA Soil Screening Guidance could also be used for RCRA Corrective Action sites as action levels. The RCRA Corrective Action program views action levels as generally fulfilling the same purpose as soil screening levels. Table F.1 shows other similarities between the RCRA Corrective Action Process, CERCLA Remedial or Removal Process, and MARSSIM.

The similarities between the CERCLA Remedial Process and Removal Process have led to a number of streamlined approaches to expedite site cleanups by reducing sampling and preventing duplication of effort. One example of these approaches is the Superfund Accelerated Cleanup Model (SACM) where the concept of integrating the removal and remedial site assessment was introduced (EPA, 1993c). A memorandum from EPA, DOE, and DOD (August 22,1994) discusses guidance on accelerating and developing streamlined approaches for the cleanup of hazardous waste at federal facility sites.

Table F.1 Program Comparison

MARSSIM	CERCLA REMEDIAL PROCESS	CERCLA REMOVAL PROCESS	RCRA
Historical Site Assessment Performed to gather existing information about radiation sites. Designed to distinguish between sites that possess no potential for residual radioactivity and those that require further investigation. Performed in three stages: 1) Site Identification 2) Preliminary Investigation 3) Site Reconnaissance	Preliminary Assessment Performed to gather existing information about the site and surrounding area. The emphasis is on obtaining comprehensive information on people and resources that might be threatened by a release from the site. Designed to distinguish between sites that pose little or no threat to human health and the environment and sites that require further investigation.	Preliminary Assessment Performed in a similar manner as in the CERCLA Remedial Process. The removal preliminary assessment may be based on available information. A removal preliminary assessment may include an identification of the source, nature and magnitude of the release, evaluation by ATSDR of the threat to public health, and evaluation of factors necessary to make the determination of whether a removal is necessary.	Facility Assessment Performed to identify and gather information at RCRA facilities, make preliminary determinations regarding releases of concern and identify the need for further actions and interim measures at the facility. Performed in three stages: 1) Preliminary Review 2) Visual Site Inspection 3) Sampling Visit (if necessary) The RCRA Facility Assessment accomplishes the same objectives as the Preliminary Assessment and Site Inspection under the Superfund Process. The RCRA Facility Assessment often forms the basis for the first conceptual model of the site.
Scoping Survey Performed to provide a preliminary assessment of the radiological hazards of the site. Supports classification of all or part of the site as Class 3 areas and identifying non-impacted areas of the site. Scoping surveys provide data to complete the site prioritization scoring process for CERCLA or RCRA sites.	Site Inspection Performed to identify the substances present, determine whether hazardous substances are being released to the environment, and determine whether hazardous substances have impacted specific targets. Designed to gather information on identified sites in order to complete the Hazard Ranking System to determine whether removal actions or further investigations are necessary.	Site Inspection Performed in a similar manner as in the Remedial Process. A removal site inspection may be performed as part of the removal site evaluation (§ 300.410) if warranted. A removal site inspection may include an perimeter or on-site inspection. If the removal site evaluation shows that removal is not required, but that remedial action under § 300.430 may be necessary, a remedial site evaluation pursuant to § 300.420 would be initiated.	

Table F.1 Program Comparison

MARSSIM	CERCLA REMEDIAL PROCESS	CERCLA REMOVAL PROCESS	RCRA
Characterization Survey Performed to support planning for final status surveys to demonstrate compliance with a dose- or risk-based regulation. Objectives include determining the nature and extent of contamination at the site, as well as meeting the requirements of RI/FS and FI/CMS.	Remedial Investigation Performed to characterize the extent and type of release of contaminants. The RI is the mechanism for collecting data to characterize site conditions, determine the nature of the waste, assess risk to human health and the environment, and conduct treatability testing as necessary to evaluate the potential performance and cost of the treatment technologies that are being considered. EPA guidance presents a combined RI/FS Model Statement of Work. The RI is generally performed in seven tasks: 1) project planning (scoping): - summary of site location - history and nature of problem - history of regulatory and response actions - preliminary site boundary - development of site operations plans 2) field investigations 3) sample/analysis verification 4) data evaluation 5) assessment of risks 6) treatability study/pilot testing 7) RI reporting	Removal Action Performed once the decision has been made to conduct a removal action at the site (under § 300.415). Whenever a planning period of at least six months exists before on-site activities must be initiated, an engineering evaluation/cost analysis or its equivalent is conducted. If environmental samples are to be collected, a sampling and analysis plan is developed to provide a process for obtaining data of sufficient quality and quantity to satisfy data needs. The sampling and analysis plan consists of: 1) The field sampling plan, which describes the number, type, and location of samples and the type of analysis 2) The quality assurance project plan, which describes policy, organization, and functional activities and the data quality objectives and measures necessary to achieve adequate data for use in removal actions.	Facility Investigation Defines the presence, magnitude, extent, direction, and rate of movement of any hazardous wastes and hazardous constituents within and beyond the facility boundary. The scope is to : 1) characterize the potential pathways of contaminant migration 2) characterize the source(s) of contamination 3) define the degree and extent of contamination 4) identify actual or potential receptors 5) support the development of alternatives from which a corrective measure will be selected by the EPA The Facility Investigation is performed in seven tasks: 1) description of current conditions 2) identification of preliminary remedial measures technologies 3) FI work plan requirements - project management plan - data collection QAPP - data management plan - health and safety plan - community relations plan 4) facility investigation 5) investigation analysis 6) laboratory and bench-scale studies 7) reports

Table F.1 Program Comparison

MARSSIM	CERCLA REMEDIAL PROCESS	CERCLA REMOVAL PROCESS	RCRA
DCGLs Residual levels of radioactive material that correspond to allowable radiation dose standards are calculated (derived concentration guideline levels) and provided to the user. The survey unit is then evaluated against this radionuclide-specific DCGL. The DCGLs in this manual are for structure surfaces and soil contamination. MARSSIM does not provide equations or guidance for calculating DCGLs.	PRGs Preliminary remediation goals are developed early in the RI/FS process. PRGs may then be used as the basis for final cleanup levels based on the nine criteria in the National Contingency Plan. Soil Screening Levels (SSLs) can be used as PRGs provided conditions at a specific site are similar to those assumed in calculating the SSLs. SSLs are derived with exposure assumptions for suburban residential land use only. SSLs are based on a 10^{-6} risk for carcinogens, a hazard index quotient of 1 for noncarcinogens (child ingestion assumptions), or MCLGs, MCLs, or HBLs for the migration to groundwater. The User's Guide provides equations and guidance for calculating site-specific SSLs.	Removal Levels The removal level is established by identification of applicable or relevant and appropriate requirements (ARARs), or by health assessments. Concern is for protection of human health and the environment from the immediate hazard of a release rather than a permanent remedy.	Action Levels At certain facilities subject to RCRA corrective action, contamination will be present at concentrations (action levels) that may not justify further study or remediation. Action levels are health- or environmental-based concentrations derived using chemical-specific toxicity information and standardized exposure assumptions. The SSLs developed under CERCLA guidance can be used as action levels since the RCRA corrective action program currently views them as serving the same purpose.

Table F.1 Program Comparison

MARSSIM	CERCLA REMEDIAL PROCESS	CERCLA REMOVAL PROCESS	RCRA
No Direct Correlation (MARSSIM characterization and remedial action support surveys may provide data to the Feasibility Study or the Corrective Measures Study)	Feasibility Study The FS serves as the mechanism for the development, screening, and detailed evaluation of alternative remedial actions. As noted above, the RI and the FS are intended to be performed concurrently. However, the FS is generally considered to be composed of four general tasks. These tasks are: 1) development and screening of remedial alternatives 2) detailed analysis of alternatives 3) community relations 4) FS reporting	No Direct Correlation	Corrective Measures Study The purpose of the CMS is to identify , develop, and evaluate potentially applicable corrective measures and to recommend the corrective measures to be taken. The CMS is performed following an FI and consists of the following four tasks: 1) identification and development of the corrective measures alternatives 2) evaluation of the corrective measures alternatives 3) justification and recommendations of the corrective measures alternatives 4) reports

Table F.1 Program Comparison

MARSSIM	CERCLA REMEDIAL PROCESS	CERCLA REMOVAL PROCESS	RCRA
Remedial Action Support Survey Performed to support remediation activities and determine when a site or survey unit is ready for the final status survey. These surveys monitor the effectiveness of decontamination efforts in reducing residual radioactivity to acceptable levels. Remedial action support surveys do not include routine operational surveys conducted to support remedial activities.	Remedial Design/Remedial Action This activity includes the development of the selected remedy and implementation of the remedy through construction. A period of operation and maintenance may follow the RD/RA activities. Generally, the RD/RA includes: 1) plans and specifications - preliminary design - intermediate design - prefinal/final design - estimated cost - correlation of plans and specifications - selection of appropriate RCRA facilities - compliance with requirements of other environmental laws - equipment startup and operator training 2) additional studies 3) operation and maintenance plan 4) QAPP 5) site safety plan	No Direct Correlation	Corrective Measures Implementation The purpose of the CMI is to design, construct, operate, maintain, and monitor the performance of the corrective measures selected in the CMS. The CMI consists of four activities: 1) Corrective Measure Implementation Program Plan 2) corrective measure design - design plans and specifications - operation and maintenance plan - cost estimate - schedule - construction QA objectives - health and safety plan - design phases 3) corrective measures construction (includes a construction QA program) 4) reporting
Final Status Survey Performed to demonstrate that residual radioactivity in each survey unit satisfies the release criterion.	Long Term Remedial Assessment Closure/Post-Closure NPL De-Listing	Post-Removal Site Control Those activities that are necessary to sustain the integrity of a removal action following its conclusion.	Closure/Post-Closure

Table F.2 Data Elements for Site Visits[a]

Data Elements Common to Both Remedial and Removal Assessment	Generally Remedial Site Assessment Only	Generally Removal Assessment Only
-Current human exposure identification -Sources identification, including locations, sizes, volumes -Information on substances present -Labels on drums and containers -Containment evaluation -Evidence of releases (*e.g.*, stained soils) -Locations of wells on site and in immediate vicinity -Nearby wetlands identification -Nearby land uses -Distance measurements or estimates for wells, land uses (residences and schools), surface waters, and wetlands -Public accessibility -Blowing soils and air contaminants -Photodocumentation -Site sketch	-Perimeter survey -Number of people within 200 feet -Some sensitive environments -Review all pathways	-Petroleum releases -Fire and explosion threat -Urgency of need for response -Response and treatment alternatives evaluation -Greater emphasis on specific pathways (*e.g.*, direct contact) -Sampling

[a]From EPA, 1993c

Table F.3 Comparison of Sampling Emphasis Between Remedial Site Assessment and Removal Assessment[a]

Remedial Site Assessment Emphasis	Removal Assessment Emphasis
-Attribution to the site -Background samples -Ground water samples -Grab samples from residential soils -Surface water sediment samples -HRS factors related to surface water sample locations -Fewer samples on average (10-30) than removal assessment -Strategic sampling for HRS -Contract Laboratory Program usage -Full screening organics and inorganics analyses -Definitive analyses -Documentation, including targets and receptors -Computing HRS scores -Standardized reports	-Sampling from containers -Physical characteristics of wastes -Treatability and other engineering concerns -On-site contaminated soils -Composite and grid sampling -Rapid turnaround on analytical services -Field/screening analyses -PRP-lead removal actions -Goal of characterizing site -Focus on NCP removal action criteria

[a]From EPA, 1993c

APPENDIX G

HISTORICAL SITE ASSESSMENT INFORMATION SOURCES

This appendix provides lists of information sources often useful to site assessment. The lists are organized in two ways:

- Table G.1, beginning on page G-2, identifies information needs by category and lists appropriate information sources for each. The categories are:

  -- General site information, p. G-2
  -- Source and waste characteristics, p. G-2
  -- Ground water use and characteristics, p. G-3
  -- Surface water use and characteristics, p. G-4
  -- Soil exposure characteristics, p. G-5
  -- Air characteristics, p. G- 6

- The reverse approach is provided in Table G.2, beginning on page G-7. Categories of information sources are listed with a brief explanation of the information provided by each source. A contact is provided for additional information. The categories are:

  -- Databases, p. G-7
  -- Maps and aerial photographs, p. G-13
  -- Files, p. G-17
  -- Expert and other sources, p. G-19

More complete listings of site assessment information sources are available in the *Site Assessment Information Directory* (EPA91e).

Table G.1 Site Assessment Information Sources (Organized by Information Needed)

General Site Information	
Site Location, Latitude/Longitude CERCLIS USGS Topographic Maps State Department of Transportation Maps Site Reconnaissance USGS Global Land Information System U.S. Census Bureau Tiger Mapping Services	*Type of Operation and Site Status* EPA Regional Libraries State Environmental Agency Files Site Reconnaissance
Owner/Operator Information EPA Regional Libraries State Environmental Agency Files Local Tax Assessor	*Environmental Setting, Size of Site* USGS Topographic Maps Aerial Photographs Site Reconnaissance
Source and Waste Characteristics	
Source Types, Locations, Sizes EPA Regional Libraries State Environmental Agency Files Aerial Photographs Site Reconnaissance DOE Field Offices	*Hazardous Substances Present* EPA Regional Libraries State Environmental Agency Files RCRIS Local Health Department Local Fire Department ERAMS Local Public Works Department
Waste Types and Quantities EPA Regional Office Files State Environmental Agency Files RCRIS Local Fire Department Aerial Photographs Site Reconnaissance Aerial Radiation Surveys	

Table G.1 Site Assessment Information Sources (continued)
(Organized by Information Needed)

Ground Water Use and Characteristics	
General Stratigraphy USGS Topographic Maps U.S. Geological Survey State Geological Surveys Geologic and Bedrock Maps Local Experts Local University or College	*Private and Municipal Wells* Local Water Authority Local Health Department Local Well Drillers State Environmental Agency Files WellFax WATSTORE
Karst Terrain USGS Topographic Maps U.S. Geological Survey State Geological Surveys Geologic and Bedrock Maps Local Experts Local University or College	*Distance to Nearest Drinking Water Well* USGS Topographic Maps Local Water Authority Local Well Drillers Local Health Department WellFax WATSTORE Site Reconnaissance
Depth to Aquifer U.S. Geological Survey State Geological Surveys Geologic and Bedrock Maps Local Experts Local Well Drillers WATSTORE	*Wellhead Protection Areas* State Environmental Agency Local Water Authority Local Well Drillers Local Health Department EPA Regional Water Officials

Table G.1 Site Assessment Information Sources (continued)
(Organized by Information Needed)

Surface Water Use and Characteristics	
Surface Water Body Types USGS Topographic Maps State Department of Transportation Maps Aerial Photographs Site Reconnaissance	*Drinking Water Intakes* Local Water Authority USGS Topographic Maps U.S. Army Corps of Engineers State Environmental Agency
Distance to Nearest Surface Water Body USGS Topographic Maps State Department of Transportation Aerial Photographs Site Reconnaissance	*Fisheries* U.S. Fish and Wildlife Service State Environmental Agency Local Fish and Wildlife Officials
Surface Water Flow Characteristics U.S. Geological Survey State Environmental Agency U.S. Army Corps of Engineers STORET WATSTORE	*Sensitive Environments* USGS Topographic Maps State Department of Transportation Maps State Environmental Agency U.S. Fish and Wildlife Service Local Fish and Wildlife Officials National Wetland Inventory Maps Ecological Inventory Maps Natural Heritage Program
Flood Frequency at the Site Federal Emergency Management Agency State Environmental Agency	

Table G.1 Site Assessment Information Sources (continued)
(Organized by Information Needed)

Soil Exposure Characteristics	
Number of People Living Within 200 Feet Site Reconnaissance USGS Topographic Maps Aerial Photographs U.S. Census Bureau Tiger Mapping Service	*Schools or Day Care Within 200 Feet* Site Reconnaissance USGS Topographic Maps Local Street Maps
Number of Workers Onsite Site Reconnaissance Owner/Operator Interviews	*Locations of Sensitive Environment* USGS Topographic State Department of Transportation Maps State Environmental Agency U.S. Fish and Wildlife Service Ecological Inventory Maps Natural Heritage Program

Table G.1 Site Assessment Information Sources (continued)
(Organized by Information Needed)

Air Pathway Characteristics	
Populations Within Four Miles GEMS NPDC USGS Topographic Maps Site Reconnaissance U.S. Census Bureau Tiger Mapping Services	*Locations of Sensitive Environments, Acreage of Wetlands* USGS Topographic Maps State Department of Transportation Maps State Environmental Agency U.S. Fish and Wildlife Service National Wetland Inventory Maps Ecological Inventory Maps Natural Heritage Program
Distance to Nearest Individual USGS Topographic Maps Site Reconnaissance	

Table G.2 Site Assessment Information Sources (Organized by Information Source)

Databases	
Source:	CERCLIS (Comprehensive Environmental Response, Compensation, and Liability Information System)
Provides:	EPA's inventory of potential hazardous waste sites. Provides site name, EPA identification number, site address, and the date and types of previous investigations
Supports:	General Site Information
Contact:	U.S. Environmental Protection Agency Office of Solid Waste and Emergency Response Office of Emergency and Remedial Response Mike Cullen 703/603-8881 Fax 703/603-9133
Source:	RODS (Records of Decision System)
Provides:	Information on technology justification, site history, community participation, enforcement activities, site characteristics, scope and role of response action, and remedy.
Supports:	General Site Information, Source and Waste Characteristics
Contacts:	U.S. Environmental Protection Agency Office of Solid Waste and Emergency Response Office of Emergency and Remedial Response Mike Cullen 703/603-8881 Fax 703/603-9133

Table G.2 Site Assessment Information Sources (continued)
(Organized by Information Source)

Databases	
Source:	RCRIS (Resource Conservation and Recovery Information System)
Provides:	EPA's inventory of hazardous waste generators. Contains facility name, address, phone number, and contact name; EPA identification number; treatment, storage and disposal history; and date of notification.
Supports:	General Site Information, Source and Waste Characteristics
Contacts:	U.S. Environmental Protection Agency Office of Solid Waste and Emergency Response Office of Solid Waste Kevin Phelps 202/260-4697 Fax 202/260-0284
Source:	ODES (Ocean Data Evaluation System)
Provides:	Information associated with both marine and fresh water supplies with the following programs: •301(h) sewage discharge •National Pollutant Discharge Elimination System (NPDES) •Ocean Dumping •National Estuary Program •403c Industrial Discharge •Great Lakes Remedial Action Program •National Coastal Waters Program Houses a variety of data pertaining to water quality, oceanographic descriptions, sediment pollutants, physical/chemical characteristics, biological characteristics, and estuary information.
Supports:	General Site Information, Source and Waste Characteristics, Surface Water Use and Characteristics
Contact:	U.S. Environmental Protection Agency Office of Water Robert King 202/260-7026 Fax 202/260-7024

Table G.2 Site Assessment Information Sources (continued)
(Organized by Information Source)

Databases	
Source:	EMMI (Environmental Monitoring Methods Index)
Provides:	U.S. Environmental Protection Agency's official methods compendium. Serves as a source of standard analytical methods.
Supports:	General Site Information
Contact:	U.S. Environmental Protection Agency User Support 703/519-1222 Annual updates may be purchased from the National Technical Information Service at 703/487-4650
Source:	WellFax
Provides:	National Water Well Association's inventory of municipal and community water supplies. Identifies public and private wells within specified distances around a point location and the number of households served by each.
Supports:	Ground Water Use and Characteristics
Contact:	National Water Well Association (NWWA) 6375 Riverside Drive Dublin, OH 43017
Source:	Geographic Resources Information Data System (GRIDS)
Provides:	National access to commonly requested geographic data products such as those maintained by the U.S. Geologic Survey, the Bureau of the Census, and the U.S. Fish and Wildlife Service.
Supports:	General Site Information, Ground Water Use and Characteristics, Surface Water Use and Characteristics, Soil Exposure Characteristics, Air Pathway Characteristics
Contact:	U.S. Environmental Protection Agency Office of Administration and Resources Management Office of Information Resources Management Bob Pease 703/235-5587 Fax 703/557-3186

Table G.2 Site Assessment Information Sources (continued)
(Organized by Information Source)

Databases	
Source:	National Planning Data Corporation (NPDC)
Provides:	Commercial database of U.S. census data. Provides residential populations in specified distance rings around a point location.
Supports:	Soil Exposure Characteristics, Air Pathway Characteristics
Contact:	National Planning Data Corporation 20 Terrace Hill Ithaca, NY 14850-5686
Source:	STORET (Storage and Retrieval of U.S. Waterways Parametric Data)
Provides:	EPA's repository of water quality data for waterways within the U.S. The system is capable of performing a broad range of reporting, statistical analysis, and graphics functions.
Supports:	Geographic and descriptive information on various waterways; analytical data from surface water, fish tissue, and sediment samples; stream flow data.
Contact:	U.S. Environmental Protection Agency Office of Water Office of Wetlands, Oceans, and Watersheds and Office of Information Resources Management Louie H. Hoelman 202/260-7050 Fax 202/260-7024

Table G.2 Site Assessment Information Sources (continued)
(Organized by Information Source)

Databases	
Source:	Federal Reporting Data System (FRDS)
Provides:	General information on public water supplies, including identification information, noncompliance related events, violations of the State Drinking Water Act, enforcement actions, identification of significant noncompliers, and information on variances, exemptions, and waivers.
Supports:	Ground Water Use and Characteristics, Surface Water Use and Characteristics
Contact:	U.S. Environmental Protection Agency Office of Water Office of Ground Water and Drinking Water Abe Seigel 202/260-2804 Fax 202/260-3464
Source:	WATSTORE
Provides:	U.S. Geological Survey's National Water Data Storage and Retrieval System. Administered by the Water Resources Division and contains the Ground Water Site Inventory file (GWSI). This provides physical, hydrologic, and geologic data about test holes, springs, tunnels, drains, ponds, other excavations, and outcrops.
Supports:	General Site Information, Ground Water Use and Characteristics, Surface Water Use and Characteristics
Contact:	U.S. Geological Surgery or USGS Regional Field Office 12201 Sunrise Valley Drive Reston, VA 22092

Table G.2 Site Assessment Information Sources (continued)
(Organized by Information Source)

Databases	
Source:	ISI (Information Systems Inventory)
Provides:	Abstracts and contacts who can provide information on U.S. Environmental Protection Agency databases.
Supports:	All information needs
Contacts:	U.S. Environmental Protection Agency Office of Information and Resources Management Information Management and Services Division ISI System Manager 202/260-5914 Fax 202/260-3923
Source:	ERAMS (Environmental Radiation Ambient Monitoring System)
Provides;	A direct assessment of the population intake of radioactive pollutants due to fallout, data for developing dose computational models, population exposures from routine and accidental releases of radioactivity from major sources, data for indicating additional measurement needs or other actions required in the event of a major release of radioactivity in the environment, and a reference for data comparison with other localized and limited monitoring programs.
Supports:	Source and waste characteristics
Contact:	U.S. Environmental Protection Agency National Air and Radiation Environmental Laboratory 540 South Morris Avenue Montgomery, AL 36115 Phone 334/270-3400 Fax 334/270-3454

Table G.2 Site Assessment Information Sources (continued)
(Organized by Information Source)

Maps and Aerial Photographs			
Source:	U.S. Geological Survey (USGS) Topographic Quadrangles		
Provides:	Maps detailing topographic, geographical, political, and cultural features. Available in 7.5- and 15-minutes series.		
Supports:	Site location and environmental setting; latitude/longitude; houses, schools, and other buildings; distances to targets; surface water body types; drainage routes; wetlands and sensitive environments; karst terrain features.		
Contacts:	U.S. Geological Survey 12201 Sunrise Valley Drive Reston, VA 22092	or	USGS Regional or Field Office
Source:	National Wetland Inventory Maps		
Provides;	Maps delineating boundaries and acreage of wetlands.		
Supports:	Environmental setting and wetlands locations.		
Contact:	U.S. Geological Survey 12201 Sunrise Valley Drive Reston, VA 22092	or	U.S. Fish and Wildlife Service 18th and C Street, NW Washington, DC 20240
Source:	Ecological Inventory Maps		
Provides:	Maps delineating sensitive environments and habitats, including special land use areas, wetlands, study areas, and native plant and animal species.		
Supports:	Environmental setting, sensitive environments, wetland locations and size.		
Contact:	U.S. Geological Survey 12201 Sunrise Valley Drive Reston, VA 22092	or	U.S. Fish and Wildlife Service 18th and C Streets, NW Washington, DC 20240

Table G.2 Site Assessment Information Sources (continued)
(Organized by Information Source)

Maps and Aerial Photographs	
Source:	Flood Insurance Rate Maps (FIRM)
Provides:	Maps delineating flood hazard boundaries for flood insurance purposes.
Supports:	Flood frequency.
Contact:	Federal Emergency Management Agency (FEMA) or Local Zoning and Planning Office Federal Insurance Administration Office of Risk Assessment 500 C Street, SW Washington, DC 20472
Source:	State Department of Transportation Maps
Provides:	State maps detailing road systems, surface water systems, and other geographical, cultural, and political features.
Supports:	Site location and environmental setting, distances to targets, wetlands, and sensitive environments.
Contact:	State or Local Government Agency
Source:	Geologic and Bedrock Maps
Provides:	Maps detailing surficial exposure and outcrop of formations for interpreting subsurface geology. Bedrock maps describe depth and lateral distribution of bedrock.
Supports:	General stratigraphy beneath and surrounding the site.
Contact:	U.S. Geological Survey or USGS Regional or Field Office 12201 Sunrise Valley Drive State Geological Survey Office Reston, VA 22092

Table G.2 Site Assessment Information Sources (continued)
(Organized by Information Source)

Maps and Aerial Photographs	
Source:	Aerial Photographs
Provides:	Black and white and/or color photographic images detailing topographic, physical, and cultural features.
Supports:	Site location and size, location and extent of waste sources, identification of surrounding surficial geology, distances to targets, wetlands and sensitive environments. May provide information on historical site operations, waste quantity, and waste handling practices.
Contact:	State Department of Transportation Local Zoning and Planning Office County Tax Assessor's Office Colleges and Universities (geology or geography departments) EPA's Environmental Monitoring Services Laboratory (EMSL) EPA's Environmental Photographic Interpretation Center (EPIC) U.S. Army Corps of Engineers U.S. Department of Agriculture, Forest Service U.S. Geological Survey
Source:	Global Land Information System (GLIS)
Provides:	An interactive computer system about the Earth's land surfaces information. GLIS contains abstract, description, and search information for each data set. Through GLIS, scientists can evaluate data sets, determine their availability, place online requests for products, or, in some cases, download products. GLIS also offers online samples of earth science data.
Supports:	Site location and environmental setting; latitude/longitude; houses, schools, and other buildings; distances to targets; surface water body types; drainage routes; wetlands and sensitive environments; karst terrain features.
Contact:	Internet: http://mapping.usgs.gov or U.S. Geological Survey 12202 Sunrise Valley Drive Reston, VA 20192, USA

Table G.2 Site Assessment Information Sources (continued)
(Organized by Information Source)

Maps and Aerial Photographs	
Source:	Topologically Integrated Geographic Encoding and Referencing (TIGER) System
Provides:	Automates the mapping and related geographic activities required to support the decennial census and sample survey programs of the U.S. Census Bureau starting with the 1990 decennial census. The topological structure of the TIGER data base defines the location and relationship of streets, rivers, railroads, and other features to each other and to the numerous geographic entities for which the Census Bureau tabulates data from its censuses and sample surveys.
Supports:	General Site Information, Soil Exposure Characteristics, Air Pathway Characteristics
Contacts:	http://www.census.gov/geo/www/tiger Public Information Office Room 2705, FB-3 Census Bureau U.S. Department of Commerce Washington, DC 20233

Table G.2 Site Assessment Information Sources (continued)
(Organized by Information Source)

Files	
Source:	Office project files
Provides:	Site investigation reports, logbooks, telecons, references, etc.
Supports:	Information on nearby sites such as town populations, public and private water supplies, well locations, targets, and general stratigraphy descriptions.
Source:	State Environmental Agency files
Provides;	Historical site information, permits, violations, and notifications.
Supports:	General site information and operational history, source descriptions, waste quantities and waste handling practices. May provide results of previous site investigations.

Table G.2 Site Assessment Information Source (continued) (Organized by Information Source)

Files		
Source:	EPA Regional Libraries	
Provides:	Historical information on CERCLIS sites, permits, violations, and notification. Additionally provides interlibrary loan services.	
Supports:	General site information and operational history, source descriptions, waste quantities and waste handling practices. May provide results of previous site investigations.	
Contact:	USEPA Region 1 Library JFK Federal Building Boston, MA 02203 617/565-3300 USEPA Region 2 Library 290 Broadway 16th Floor New York, NY 10007-1866 212/264-2881 USEPA Region 3 Information Resources Center, 3PM52 841 Chestnut Street Philadelphia, PA 19107 215/597-0580 USEPA Region 4 Library Atlanta Federal Center 61 Forsyth Street, SW Atlanta, GA 30303-8909 404/562-8190 USEPA Region 5 Library 77 W. Jackson Blvd., 12th Floor Chicago, IL 60604-3590 312/353-2022	USEPA Region 6 Library, 6M-A1 1445 Ross Avenue, Suite 1200 First Interstate Bank Tower Dallas, TX 75202-2733 214/655-6427 USEPA Region 7 Information Resources Center 726 Minnesota Avenue Kansas City, KS 66101 913/551-7358 USEPA Region 8 Library, 8PM-IML 999 18th Street Suite 500 Denver, CO 80202-2405 303/293-1444 USEPA Region 9 Library, MS:P-5-3 75 Hawthorne Street San Francisco, CA 94105 415/744-1510 USEPA Region 10 Library, MD-108 1200 Sixth Avenue Seattle, WA 98101 206/553-1289 or 1259

Table G.2 Site Assessment Information Sources (continued)
(Organized by Information Source)

Expert and Other Sources	
Source:	U.S. Geological Survey
Provides:	Geologic, hydrogeologic, and hydraulic information including maps, reports, studies, and databases.
Supports:	General stratigraphy descriptions, karst terrain, depth to aquifer, stream flow, ground water and surface water use and characteristics.
Contact:	U.S. Geological Survey or USGS Regional or Field Office 12201 Sunrise Valley Drive Reston, VA 22092
Source:	U.S. Army Corps of Engineers
Provides:	Records and data surrounding engineering projects involving surface waters.
Supports:	Ground water and surface water characteristics, stream flow, locations of wetlands and sensitive environments.
Contact:	U.S. Army Corps of Engineers
Source:	State Geological Survey
Provides:	State-specific geologic and hydrogeologic information including maps, reports, studies, and databases.
Supports:	General stratigraphy descriptions, karst terrain, depth to aquifer, ground water use and characteristics.
Contact:	State Geological Survey (Local or Field Office)
Source:	Natural Heritage Program
Provides:	Information on Federal and State designated endangered and threatened plants, animals, and natural communities. Maps, lists and general information may be available.
Supports:	Location of sensitive environments and wetlands.
Contact:	State Environmental Agency

Table G.2 Site Assessment Information Sources (continued)
(Organized by Information Source)

Expert and Other Sources	
Source:	U.S. Fish and Wildlife Service
Provides:	Environmental Information
Supports:	Locations of sensitive environments, wetlands, fisheries; surface water characteristics and stream flow.
Contact:	U.S. Fish and Wildlife Service 18th and C Streets, NW Washington, DC 20240 or U.S. Fish and Wildlife Service Regional office
Source:	Local Fish and Wildlife Officials
Provides:	Local Environmental Information
Supports:	Locations of sensitive environments, wetlands, fisheries; surface water characteristics and stream flow.
Contact:	State or Local Environmental Agency State or Local Game or Conservation Office
Source:	Local Tax Assessor
Provides:	Past and present land ownership records, lot and building sizes, assessors maps. May also provide historical aerial photographs.
Supports:	Name of present and past owners/operators, years of ownership, size of site, and operational history.
Contact:	Local Town Government Office

Table G.2 Site Assessment Information Sources (continued)
(Organized by Information Source)

Expert and Other Sources	
Source:	Local Water Authority
Provides:	Public and private water supply information, including service area maps, well locations and depths, well logs, surface water intake locations, information regarding water supply contamination.
Supports:	Locations and populations served by municipal and private drinking water sources (wells and surface water intakes), pumpage and production, blended systems, depth to aquifer, general stratigraphic descriptions, ground water and surface water characteristics, stream flow.
Contact:	Local Town Government Office
Source:	Local Health Department
Provides:	Information and reports regarding health-related problems that may be associated with a site. Information on private and municipal water supplies, and onsite monitoring wells.
Supports:	Primary/secondary targets differentiation, locations and characteristics of public substances present at the site.
Contact:	Local Town Government Office
Source:	Local Zoning Board or Planning Commission
Provides:	Records of local land development, including historical land use and ownership, and general stratigraphy descriptions.
Supports:	General site description and history, previous ownership, and land use.
Contact:	Local Town Government Office

Table G.2 Site Assessment Information Sources (continued)
(Organized by Information Source)

Expert and Other Sources	
Source:	Local Fire Department
Provides:	Records of underground storage tanks in the area, material safety data sheets (MSDS) for local commercial and industrial businesses, and other information on hazardous substances used by those businesses.
Supports:	Location and use of underground storage tanks and other potential sources of hazardous substances, identification of hazardous substances present at the site.
Contact:	Local Town Government Office
Source:	Local Well Drillers
Provides:	Public and Private water supply information including well locations and depths, well logs, pumpage and production.
Supports:	Populations served by private and municipal drinking water wells, depth to aquifer, general stratigraphic information.
Source:	Local University or College
Provides:	Geology/Environmental Studies departments may have relevant published materials (reports, theses, dissertations) and faculty experts knowledgeable in local geologic, hydrologic, and environmental conditions.
Supports:	General stratigraphic information, ground water and surface water use and characteristics, stream flow.
Source:	Site Reconnaissance
Provides:	Onsite and /or offsite visual observation of the site and surrounding area.
Supports:	General site information; source identification and descriptions; general ground water, surface water, soil, and air pathway characteristics; nearby targets; probable point of entry to surface water.

APPENDIX H

DESCRIPTION OF FIELD SURVEY AND LABORATORY ANALYSIS EQUIPMENT

H.1 INTRODUCTION

This appendix provides information on various field and laboratory equipment used to measure radiation levels and radioactive material concentrations. The descriptions provide general guidance, and those interested in purchasing or using the equipment are encouraged to contact vendors and users of the equipment for specific information and recommendations. Although most of this equipment is in common use, a few specialty items are included to demonstrate promising developments.

The equipment is divided into two broad groupings of field survey and laboratory instruments, and each group is subdivided into equipment that measures alpha, beta, gamma, x-rays, and radon. A single sheet provides information for each system and includes its type of use (field or lab), the primary and secondary radiation detected, applicability for site surveys, operation, specificity/sensitivity, and cost of the equipment and surveys performed.

The Applicability for Site Surveys section discusses how the equipment is most useful for performing site radiological surveys. The Operation section provides basic technical information on what the system includes, how it works, how to use it practically in the field, and its features. The Specificity/Sensitivity section addresses the system's strengths and weaknesses, and the levels of radioactivity it can measure. Information for the Cost section was obtained primarily from discussions with manufacturers, users, and reviews of product literature. The cost per measurement is an estimate of the cost of producing and documenting a single data point, generally as part of a multipoint survey. It assumes times for instrument calibration (primarily if conducted at the time of the survey), use, sample analysis, and report preparation and review. It should be recognized that these values will change over time due to factors like inflation and market expansion.

It is assumed that the user of this appendix has a basic familiarity with field and laboratory equipment. Some of the typical instrument features and terms are listed below and may not be described separately for the individual instruments:

- Field survey equipment consists of a detector, a survey meter, and interconnected cables, although these are sometimes packaged in a single container. **The detector** or probe is the portion which is sensitive to radiation. It is designed in such a manner, made of selected materials, and operated at a high voltage that makes it sensitive to one or more types of radiation. Some detectors feature a window or a shield whose construction material and thickness make the detector more or less sensitive to a particular radiation. The size of the detector can vary depending on the specific need, but is often limited by the characteristics of the construction materials and the physics of the detection process. **The survey meter** contains the electronics and provides high voltage to the detector, processes the detector's signal, and displays the readings in analog or digital fashion. An analog survey meter has a continuous swing needle and typically a manually operated

scale switch, used to keep the needle on scale. The scaling switch may not be required on a digital survey meter. **The interconnecting cables** serve to transfer the high voltage and detector signals in the proper direction. These cables may be inside those units which combine the meter and detector into a single box, but they are often external with connectors that allow the user to interchange detectors.

- Scanning and measuring surveys. In a scanning survey, the field survey meter is operated while moving the detector over an area to search for a change in readings. Since the meter's audible signal responds faster than the meter display, listening to the built-in speaker or using headphones allows the user to more quickly discern changes in radiation level. When a scanning survey detects a change, the meter can be held in place for a more accurate static measurement.

- Integrated readings. Where additional sensitivity is desired, the reading can be integrated using internal electronics or an external scaler to give total values over time. The degree to which the sensitivity can be improved depends largely on the integration time selected.

- Units of measure. Survey meters with conventional meter faces measure radiation levels in units of counts, microRoentgen (μR), millirad (mrad), or millirem (mrem) in terms of unit time, *e.g.*, cpm or μR/hr. Those with SI meter faces use units of microSievert (μSv) or milliGray per unit time, *e.g.*, μSv/hr or mGy/hr.

H.2 FIELD SURVEY EQUIPMENT

H.2.1 Alpha Particle Detectors

System: ALPHA SCINTILLATION SURVEY METER
Lab/Field: Field
Radiation Detected: **Primary:** Alpha **Secondary**: None (in relatively low gamma fields)

Applicability to Site Surveys: The alpha scintillation survey meter is useful for determining the presence or absence of alpha-emitting contamination on nonporous surfaces, swipes, and air filters, or on irregular surfaces if the degree of surface shielding is known.

Operation: This survey meter uses an alpha radiation detector with a sensitive area of approximately 50 to 100 cm^2 (8 to 16 $in.^2$). The detector has a thin, aluminized window of mylar that blocks ambient light but allows alpha radiation to pass through. The detecting medium is silver activated zinc sulfide, ZnS(Ag). When the discriminator is appropriately adjusted, the meter is sensitive only to alpha radiation. Light pulses are amplified by a photomultiplier tube and passed to the survey meter.

The probe is generally placed close to the surface due to the short range of alpha particles in air. A scanning survey is used to identify areas of elevated surface contamination and then a direct survey is performed to obtain actual measurements. Integrating the readings over time improves the sensitivity enough to make the instrument very useful for alpha surface contamination measurements for many isotopes. The readings are displayed in counts per minute, but factors can usually be obtained to convert readings from cpm to dpm. Conversion factors, however, can be adversely affected by the short range of alpha particles which allows them to be shielded to often uncertain degrees if they are embedded in the surface. Systems typically use 2 to 6 "C" or "D" cells and will operate for 100-300 hours.

Specificity/Sensitivity: When the alpha discriminator is correctly adjusted, the alpha scintillation survey meter measures only alpha radiation, even if there are other radiations present. A scanning survey gives a quick indication of the presence or absence of surface contamination, while integrating the readings provides a measure of the activity on a surface, swipe, or filter. Alpha radiation is easily adsorbed by irregular, porous, moist, or over painted surfaces, and this should be carefully considered when converting count rate data to surface contamination levels. This also requires wet swipes and filters to be dried before counting. The minimum sensitivity is around 10 cpm using the needle deflection or 1 to 2 cpm when using headphones or a scaler. Some headphones or scalers give one click for every two counts, so the manual should be consulted to preclude underestimating the radioactivity by a factor of two.

Cost of Equipment: $1000

Cost per Measurement: $5

System: ALPHA TRACK DETECTOR
Lab/Field: Field and Indoor Surfaces
Radiation Detected: **Primary:** Alpha **Secondary:** None

Applicability to Site Surveys: Alpha track detectors measure gross alpha surface contamination, soil activity levels, or the depth profile of contamination.

Operation: This is a passive integrating detector. It consists of a 1 mm-thick sheet of polycarbonate material which is deployed directly on the soil surface or in close proximity to the contaminated surface. When alpha particles strike the detector surface, they cause microscopic damage centers to form in the plastic matrix. After deployment, the detector is etched in a caustic solution which preferentially attacks the damage centers. The etch pits may then be counted in an optical scanner. The density of etch pits, divided by the deployment time, is proportional to the soil or surface alpha activity. The measurement may be converted to isotopic concentration if the isotopes are known or measured separately. The area of a standard detector is 2 cm^2 (0.3 $in.^2$), but it may be cut into a variety of shapes and sizes to suit particular needs.

Specificity/Sensitivity: Alpha track detectors are relatively inexpensive, simple, passive, and have no measurable response to beta/gamma radiation. They provide a gross alpha measurement where the lower limit of detection is a function of deployment time. For surface contamination it is 330 Bq/m^2 (200 dpm/100cm^2) @ 1 hour, 50 Bq/m^2 (30 dpm/100cm^2) @ 8 hours, and 17 Bq/m^2 (10 dpm/100cm^2) @ 48 hours. For soil contamination it is 11,000 Bq/kg (300 pCi/g) @ 1 hour, 3,700 Bq/kg (100 pCi/g) @ 8 hours, and 740 Bq/kg (20 pCi/g) @ 96 hours. High surface contamination or soil activity levels may be measured with deployment times of a few minutes, while activity down to background levels may require deployment times of 48-96 hours. When placed on a surface, they provide an estimate of alpha surface contamination or soil concentration. When deployed against the side of a trench, they can provide an estimate of the depth profile of contamination. They may also be used in pipes and under/inside of equipment.

For most applications, the devices are purchased for a fixed price per measurement, which includes readout. This requires that the detectors be returned to the vendor and the data are not immediately available. For programs having continuing needs and a large number of measurements, automated optical scanners may be purchased. The cost per measurement is then a function of the number of measurements required.

Cost of Equipment: $65,000

Cost per Measurement: $5 to $10

System: ELECTRET ION CHAMBER
Lab/Field: Field
Radiation Detected: **Primary:** Alpha, beta, gamma, or radon **Secondary:** None
Applicability to Site Surveys: An electret is a passive integrating detector for measurements of alpha- or beta-emitting contaminants on surfaces and in soils, gamma radiation dose, or radon air concentration.

Operation: The system consists of a charged Teflon disk (electret), open-faced ionization chamber, and electret voltage reader/data logger. When the electret is screwed into the chamber, a static electric field is established and a passive ionization chamber is formed. For alpha or beta radiation, the chamber is opened and deployed directly on the surface or soil to be measured so the particles can enter the chamber. For gammas, however, the chamber is left closed and the gamma rays incident on the chamber penetrate the 2 mm-thick plastic detector wall. These particles or rays ionize the air molecules, the ions are attracted to the charged electret, and the electret's charge is reduced. The electret charge is measured before and after deployment with the voltmeter, and the rate of change of the charge is proportional to the alpha or beta surface or soil activity, with appropriate compensation for background gamma levels. A thin Mylar window may be used to protect the electret from dust. In low-level gamma measurements, the electret is sealed inside a Mylar bag during deployment to minimize radon interference. For alpha and beta measurements, corrections must be made for background gamma radiation and radon response. This correction is accomplished by deploying additional gamma or radon-sensitive detectors in parallel with the alpha or beta detector. Electrets are simple and can usually be reused several times before recharging by a vendor. Due to their small size (3.8 cm tall by 7.6 cm diameter or 1.5 in. tall by 3 in. diameter), they may be deployed in hard-to-access locations.

Specificity/Sensitivity: This method gives a gross alpha, gross beta, gross gamma, or gross radon measurement. The lower limit of detection depends on the exposure time and the volume of the chamber used. High surface alpha or beta contamination levels or high gamma radiation levels may be measured with deployment times of a few minutes. Much lower levels can be measured by extending the deployment time to 24 hours or longer. For gamma radiation, the response of the detector is nearly independent of energy from 15 to 1200 keV, and fading corrections are not required. To quantify ambient gamma radiation fields of 10 μR/hr, a 1000 mL chamber may be deployed for two days or a 50 mL chamber deployed for 30 days. The smallest chamber is particularly useful for long-term monitoring and reporting of monthly or quarterly measurements. For alpha and beta particles, the measurement may be converted to isotopic concentration if the isotopes are known or measured separately. The lower limit of detection for alpha radiation is 83 Bq/m^2 (50 dpm/100 cm^2) @ 1 hour, 25 Bq/m^2 (15 dpm/100 cm^2) @ 8 hours, and 13 Bq/m^2 (8 dpm/100 cm) @ 24 hours. For beta radiation from tritium it is 10,000 Bq/m^2 (6,000 dpm/cm^2) @ 1 hour and 500 Bq/m^2 (300 dpm/cm^2) @ 24 hours. For beta radiation from ^{99}Tc it is 830 Bq/m^2 (500 dpm/cm^2) @ 1 hour and 33 Bq/m^2 (20 dpm/cm^2) @ 24 hours.

Cost of Equipment: $4,000 to $25,000, for system if purchased.
Cost per Measurement: $8-$25, for use under service contract

System: GAS-FLOW PROPORTIONAL COUNTER
Lab/Field: Field
Radiation Detected: **Primary:** Alpha, Beta **Secondary:** Gamma
Applicability to Site Surveys: This equipment measures gross alpha or gross beta/gamma surface contamination levels on relatively flat surfaces like the floors and walls of facilities. It also serves as a screen to determine whether or not more nuclide-specific analyses may be needed.
Operation: This system consists of a gas-flow proportional detector, gas supply, supporting electronics, and a scaler or rate meter. Small detectors (~100 cm^2) are hand-held and large detectors (~400-600 cm^2) are mounted on a rolling cart. The detector entrance window can be <1 to almost 10 mg/cm^2 depending on whether alpha, alpha-beta, or gamma radiation is monitored. The gas used is normally P-10, a mixture of 10% methane and 90% argon. The detector is positioned as close as practical to the surface being monitored for good counting efficiency without risking damage from the detector touching the surface. Quick disconnect fittings allow the system to be disconnected from the gas bottle for hours with little loss of counting efficiency. The detector operating voltage can be set to make it sensitive only to alpha radiation, to both alpha and beta radiation, or to beta and low energy gamma radiation. These voltages are determined for each system by placing either an alpha source, such as ^{230}Th or ^{241}Am, or a beta source, such as ^{90}Sr, facing and near the detector window, then increasing the high voltage in incremental steps until the count rate becomes constant. The alpha plateau, the region of constant count rate, will be almost flat. The beta plateau will have a slope of 5 to 15 percent per 100 volts. Operation on the beta plateau allows detection of some gamma radiation, but the efficiency is very low. Some systems use a spectrometer to separate alpha, and beta/gamma events, allowing simultaneous determination of both the alpha and beta/gamma surface contamination levels.
Specificity/Sensitivity: These systems do not identify the alpha or beta energies detected and cannot be used to identify specific radionuclides. Background for operation on the alpha plateau is very low, 2 to 3 counts per minute, which is higher than for laboratory detectors because of the larger detector size. Background for operation on the beta plateau is dependent on the ambient gamma and cosmic ray background, and typically ranges from several hundred to a thousand counts per minute. Typical efficiencies for unattenuated alpha sources are 15-20%. Beta efficiency depends on the window thickness and the beta energy. For $^{90}Sr/^{90}Y$ in equilibrium, efficiencies range from 5% for highly attenuated to about 35% for unattenuated sources. Typical gamma ray efficiency is <1%. The presence of natural radionuclides in the surfaces could interfere with the detection of other contaminants. Unless the nature of the contaminant and any naturally-occurring radionuclides is well known, this system is better used for assessing gross surface contamination levels. The texture and porosity of the surface can hide or shield radioactive material from the detector, causing levels to be underestimated. Changes in temperature can affect the detectors's sensitivity. Incomplete flushing with gas can cause a nonuniform response over the detector's surface. Condensation in the gas lines or using the quick disconnect fittings can cause count rate instability.
Cost of Equipment: $2,000 to $4,000
Cost per Measurement: $2-$10 per m^2

System: LONG RANGE ALPHA DETECTOR (LRAD)
Lab/Field: Field
Radiation Detected: **Primary:** Alpha **Secondary:** None

Applicability to Site Surveys: The LRAD is a rugged field-type unit for measuring alpha surface soil concentration over a variety of dry, solid, flat terrains.

Operation: The LRAD system consists of a large (1 m x 1 m) aluminum box, open on the bottom side, containing copper plates that collect ions produced in the soil or surface under the box, and used to measure alpha surface contamination or soil concentration. It is attached to a lifting device on the front of a tractor and can be readily moved to new locations. Bias power is supplied by a 300-V dry cell battery, and the electrometer and computer are powered by an automobile battery and DC-to-AC inverter. A 50 cm grounding rod provides electrical grounding. A notebook computer is used for data logging and graphical interpretation of the data. Alpha particles emitted by radionuclides in soil travel only about 3 cm in air. However, these alpha particles interact with the air and produce ions that travel considerably farther. The LRAD detector box is lowered to the ground to form an enclosed ionization region. The copper detector plate is raised to +300V along with a guard detector mounted above the detector plate to control leakage current. The ions are then allowed to collect on the copper plate producing a current that is measured with a sensitive electrometer. The signal is then averaged and processed on a computer. The electric current produced is proportional to the ionization within the sensitive area of the detector and to the amount of alpha contamination present on the surface soil.

Due to its size and weight (300 lb), the unit can be mounted on a tractor for ease of movement. All metal surfaces are covered with plastic to reduce the contribution from ion sources outside the detector box. At each site, a ground rod is driven into the ground. Each location is monitored for at least 5 min. After each location is monitored, its data is fed into a notebook computer and an interpolative graph of alpha concentration produced. The unit is calibrated using standard alpha sources.

Sensitivity/Specificity: The terrain over which this system is used must be dry, to prevent the shielding of alpha particles by residual moisture, and flat, to prevent air infiltration from outside the detector, both of which can lead to large errors. The unit can detect a thin layer of alpha surface contamination at levels of 33-83 Bq/m^2 (20-50 dpm/100 cm^2), but does not measure alpha contamination of deeper layers. Alpha concentration errors are $\pm$74-740 Bq/kg ($\pm$2-20 pCi/g), with daily repeat accuracies of $\pm$370-3,700 Bq/kg ($\pm$10-100 pCi/g), depending on the contamination level. The dynamic measurement range appears to be 370-110,00 Bq/kg (10-3,000 pCi/g).

Cost of Equipment: $25,000 (est. for tractor, computer, software, electrometer, and detector)
Cost per Measurement: $80 (based on 30 min per point and a 2 person team)

H.2 FIELD SURVEY EQUIPMENT

H.2.2 Beta Particle Detectors

System: ELECTRET ION CHAMBER
Lab/Field: Field
Radiation Detected: **Primary:** Low energy beta (*e.g.* tritium, ^{99}Tc, ^{14}C, ^{90}Sr, ^{63}Ni), alpha, gamma, or radon **Secondary:** None

Applicability to Site Surveys: This system measures alpha- or beta-emitting contaminants on surfaces and in soils, gamma radiation dose, or radon air concentration, depending on how it is configured.

Operation: The system consists of a charged Teflon disk (electret), open-faced ionization chamber, and electret voltage reader/data logger. When the electret is screwed into the chamber, a static electric field is established and a passive ionization chamber is formed. For alpha or beta radiation, the chamber is opened and deployed directly on the surface or soil to be measured so the particles can enter the chamber. For gammas, however, the chamber is left closed and the gamma rays incident on the chamber penetrate the 2 mm-thick plastic detector wall. These particles or rays ionize the air molecules, the ions are attracted to the charged electret, and the electret's charge is reduced. The electret charge is measured before and after deployment with the voltmeter, and the rate of change of the charge is proportional to the alpha or beta surface or soil activity, with appropriate compensation for background gamma levels. A thin Mylar window may be used to protect the electret from dust. In low-level gamma measurements, the electret is sealed inside a Mylar bag during deployment to minimize radon interference. For alpha and beta measurements, corrections must be made for background gamma radiation and radon response. This correction is accomplished by deploying additional gamma or radon-sensitive detectors in parallel with the alpha or beta detector. Electrets are simple and can usually be reused several times before recharging by a vendor. Due to their small size (3.8 cm tall by 7.6 cm diameter or 1.5 in. tall by 3 in. diameter), they may be deployed in hard-to-access locations.

Specificity/Sensitivity: This method gives a gross alpha, gross beta, gross gamma, or gross radon measurement. The lower limit of detection depends on the exposure time and the volume of the chamber used. High surface alpha or beta contamination levels or high gamma radiation levels may be measured with deployment times of a few minutes. Much lower levels can be measured by extending the deployment time to 24 hours or longer. For gamma radiation, the response of the detector is nearly independent of energy from 15 to 1200 keV, and fading corrections are not required. To quantify ambient gamma radiation fields of 10 μR/hr, a 1000 mL chamber may be deployed for two days or a 50 mL chamber deployed for 30 days. The smallest chamber is particularly useful for long-term monitoring and reporting of monthly or quarterly measurements. For alpha and beta particles, the measurement may be converted to isotopic concentration if the isotopes are known or measured separately. The lower limit of detection for alpha radiation is 83 Bq/m^2 (50 dpm/100 cm^2) @ 1 hour, 25 Bq/m^2 (15 dpm/100 cm^2) @ 8 hours, and 13 Bq/m^2 (8 dpm/100 cm^2) @ 24 hours. For beta radiation from tritium it is 10,000 Bq/m^2 (6,000 dpm/cm^2) @ 1 hour and 500 Bq/m^2 (300 dpm/cm^2) @ 24 hours. For beta radiation from ^{99}Tc it is 830 Bq/m^2(500 dpm/cm^2) @ 1 hour and 33 Bq/m^2 (20 dpm/cm^2) @ 24 hours.

Cost of Equipment: $4,000 to $25,000, for system if purchased.

Cost per Measurement: $8-$25, for use under service contract

System: GAS-FLOW PROPORTIONAL COUNTER
Lab/Field: Field
Radiation Detected: **Primary:** Alpha, Beta **Secondary:** Gamma
Applicability to Site Surveys: This equipment measures gross alpha or gross beta/gamma surface contamination levels on relatively flat surfaces like the floors and walls of facilities. It would serve as a screen to determine whether or not more nuclide-specific analyses were needed.
Operation: This system consists of a gas-flow proportional detector, gas supply, supporting electronics, and a scaler or rate meter. Small detectors (~100 cm^2) are hand-held and large detectors (~400-600 cm^2) are mounted on a rolling cart. The detector entrance window can be <1 to almost 10 mg/cm^2 depending on whether alpha, alpha-beta, or gamma radiation is monitored. The gas used is normally P-10, a mixture of 10% methane and 90% argon. The detector is positioned as close as practical to the surface being monitored for good counting efficiency without risking damage from the detector touching the surface. Quick disconnect fittings allow the system to be disconnected from the gas bottle for hours with little loss of counting efficiency. The detector operating voltage can be set to make it sensitive only to alpha radiation, to both alpha and beta radiation, or to beta and low energy gamma radiation. These voltages are determined for each system by placing either an alpha source, such as ^{230}Th or ^{241}Am, or a beta source, such as ^{90}Sr, facing and near the detector window, then increasing the high voltage in incremental steps until the count rate becomes constant. The alpha plateau, the region of constant count rate, will be almost flat. The beta plateau will have a slope of 5 to 15 percent per 100 volts. Operation on the beta plateau allows detection of some gamma radiation, but the efficiency is very low. Some systems use a spectrometer to separate alpha, and beta/gamma events, allowing simultaneous determination of both the alpha and beta/gamma surface contamination levels.
Specificity/Sensitivity: These systems do not identify the alpha or beta energies detected and cannot be used to identify specific radionuclides. Background for operation on the alpha plateau is very low, 2 to 3 counts per minute, which is higher than for laboratory detectors because of the larger detector size. Background for operation on the beta plateau is dependent on the ambient gamma and cosmic ray background, and typically ranges from several hundred to a thousand counts per minute. Typical efficiencies for unattenuated alpha sources are 15-20%. Beta efficiency depends on the window thickness and the beta energy. For $^{90}Sr/^{90}Y$ in equilibrium, efficiencies range from 5% for highly attenuated to about 35% for unattenuated sources. Typical gamma ray efficiency is <1%. The presence of natural radionuclides in the surfaces could interfere with the detection of other contaminants. Unless the nature of the contaminant and any naturally-occurring radionuclides is well known, this system is better used for assessing gross surface contamination levels. The texture and porosity of the surface can hide or shield radioactive material from the detector, causing levels to be underestimated. Changes in temperature can affect the detectors's sensitivity. Incomplete flushing with gas can cause a nonuniform response over the detector's surface. Condensation in the gas lines or using the quick disconnect fittings can cause count rate instability.
Cost of Equipment: $2,000 to $4,000
Cost per Measurement: $2-$10 per m^2

System: GM SURVEY METER WITH BETA PANCAKE PROBE
Lab/Field: Field
Radiation Detected: **Primary:** Beta **Secondary:** Gamma and alpha
Applicability to Site Surveys: This instrument is used to find and measure low levels of beta/gamma contamination on relatively flat surfaces.
Operation: This instrument consists of a flat "pancake" type Geiger-Mueller detector connected to a survey meter which measures radiation response in counts per minute. The detector housing is typically a rigid metal on all sides except the radiation entrance face or window, which is made of Mylar, mica, or a similar material. A steel, aluminum, lead, or tungsten housing surrounds the detector on all sides except the window, giving the detector a directional response. The detector requires approximately 900 volts for operation. It is held within a few cm of the surface to minimize the thickness of air shielding in between the radioactive material and the detector. It is moved slowly to scan the surface in search of elevated readings, then held in place long enough to obtain a stable measurement. Radiation entering the detector ionizes the gas, causes a discharge throughout the entire tube, and results in a single count being sent to the meter. The counts per minute meter reading is converted to a beta surface contamination level in the range of 1,700 Bq/m^2 (1,000 dpm/100 cm^2) using isotope specific factors.

Specificity/Sensitivity: Pancake type GM detectors primarily measure beta count rate in close contact with surfaces to indicate the presence of contamination. They are sensitive to any alpha, beta, or gamma radiation that enters the detector and causes ionization. As a result, they cannot determine the type or energy of that radiation, except by using a set of absorbers. To be detected, beta particles must have enough energy to penetrate through any surface material that the contamination is absorbed in, plus the detector window, and the layer of air and other shielding materials in between. Low energy beta particles from emitters like ^{3}H (17 keV) that cannot penetrate the window alone are not detectable, while higher energy betas like those from ^{60}Co (314 keV) can be readily detected. The beta detection efficiency at a field site is primarily a function of the beta energy, window thickness, and the surface condition. The detection sensitivity can be improved by using headphones or the audible response during scans. By integrating the count rate over a longer period or by counting the removable radioactive material collected on a swipe , the ability to detect surface contamination can be improved. The nominal 2 in. diameter detector can measure an increase of around 100 cpm above background, which equates to 4,200 Bq/m^2 (2,500 dpm/100 cm^2) of ^{60}Co on a surface under the detector or 20 Bq (500 pCi) on a swipe. Larger 100 cm^2 detectors improve sensitivity and eliminate the need to swipe. A swipe's collection efficiency may be below 100%, and depends on the wiping technique, the actual surface area covered, the texture and porosity of the surface, the affinity of the contamination for the swipe material, and the dryness of the swipe. This will proportionately change the values above. The sensitivity to gamma radiation is around 10% or less of the beta sensitivity, while the alpha detection efficiency is difficult to evaluate.

Cost of equipment: $400 to $1,500
Cost per Measurement: $5 to $10 per location

H.2 FIELD SURVEY EQUIPMENT

H.2.3 Gamma Ray Detectors

System: ELECTRET ION CHAMBER
Lab/Field: Field
Radiation Detected: **Primary:** Low energy beta (*e.g.* tritium, ^{99}Tc, ^{14}C, ^{90}Sr, ^{63}Ni), alpha, gamma, or radon **Secondary:** None

Applicability to Site Surveys: This system measures alpha- or beta-emitting contaminants on surfaces and in soils, gamma radiation dose, or radon air concentration, depending on how it is configured.

Operation: The system consists of a charged Teflon disk (electret), open-faced ionization chamber, and electret voltage reader/data logger. When the electret is screwed into the chamber, a static electric field is established and a passive ionization chamber is formed. For alpha or beta radiation, the chamber is opened and deployed directly on the surface or soil to be measured so the particles can enter the chamber. For gammas, however, the chamber is left closed and the gamma rays incident on the chamber penetrate the 2 mm-thick plastic detector wall. These particles or rays ionize the air molecules, the ions are attracted to the charged electret, and the electret's charge is reduced. The electret charge is measured before and after deployment with the voltmeter, and the rate of change of the charge is proportional to the alpha or beta surface or soil activity, with appropriate compensation for background gamma levels. A thin Mylar window may be used to protect the electret from dust. In low-level gamma measurements, the electret is sealed inside a Mylar bag during deployment to minimize radon interference. For alpha and beta measurements, corrections must be made for background gamma radiation and radon response. This correction is accomplished by deploying additional gamma or radon-sensitive detectors in parallel with the alpha or beta detector. Electrets are simple and can usually be reused several times before recharging by a vendor. Due to their small size (3.8 cm tall by 7.6 cm diameter or 1.5 in. tall by 3 in. diameter), they may be deployed in hard-to-access locations.

Specificity/Sensitivity: This method gives a gross alpha, gross beta, gross gamma, or gross radon measurement. The lower limit of detection depends on the exposure time and the volume of the chamber used. High surface alpha or beta contamination levels or high gamma radiation levels may be measured with deployment times of a few minutes. Much lower levels can be measured by extending the deployment time to 24 hours or longer. For gamma radiation, the response of the detector is nearly independent of energy from 15 to 1200 keV, and fading corrections are not required. To quantify ambient gamma radiation fields of 10 μR/hr, a 1000 mL chamber may be deployed for two days or a 50 mL chamber deployed for 30 days. The smallest chamber is particularly useful for long-term monitoring and reporting of monthly or quarterly measurements. For alpha and beta particles, the measurement may be converted to isotopic concentration if the isotopes are known or measured separately. The lower limit of detection for alpha radiation is 83 Bq/m^2 (50 dpm/100 cm^2) @ 1 hour, 25 Bq/m^2 (15 dpm/100 cm^2) @ 8 hours, and 13 Bq/m^2 (8 dpm/100 cm^2) @ 24 hours. For beta radiation from tritium it is 10,000 Bq/m^2 (6,000 dpm/cm^2) @ 1 hour and 500 Bq/m^2 (300 dpm/cm^2) @ 24 hours. For beta radiation from ^{99}Tc it is 830 Bq/m^2(500 dpm/cm^2) @ 1 hour and 33 Bq/m^2 (20 dpm/cm^2) @ 24 hours.

Cost of Equipment: $4,000 to $25,000, for system if purchased.

Cost per Measurement: $8-$25, for use under service contract

System: GM SURVEY METER WITH GAMMA PROBE
Lab/Field: Field
Radiation Detected: **Primary:** Gamma **Secondary:** Beta

Applicability to Site Surveys: This instrument is used to give a quick indication of gamma-radiation levels present at a site. Due to its high detection limit, the GM survey meter may be useful during characterization surveys but may not meet the needs of final status surveys.

Operation: This instrument consists of a cylindrical Geiger Mueller detector connected to a survey meter. It is calibrated to measure gamma exposure rate in mR/hr. The detector is surrounded on all sides by a protective rigid metal housing. Some units called end window or side window have a hinged door or rotating sleeve that opens to expose an entry window of Mylar, mica, or a similar material, allowing beta radiation to enter the sensitive volume. The detector requires approximately 900 volts for operation. It is normally held at waist height, but is sometimes placed in contact with an item be evaluated. It is moved slowly over the area to scan for elevated readings, observing the meter or, preferably, listening to the audible signal. Then it is held in place long enough to obtain a stable measurement. Radiation entering the detector ionizes the gas, causes a discharge throughout the entire tube, and results in a single count being sent to the meter. Conversion from count rate to exposure rate is accomplished at calibration by exposing the detector at discrete levels and adjusting the meter scale(s) to read accordingly. In the field, the exposure rate is read directly from the meter. If the detector housing has an entry window , an increase in "open-door" over "closed-door" reading indicates the presence of beta radiation in the radiation field, but the difference is not a direct measure of the beta radiation level.

Specificity/Sensitivity: GM meters measure gamma exposure rate, and those with an entry window can identify if the radiation field includes beta radiation. Since GM detectors are sensitive to any energy of alpha, beta, or gamma radiation that enters the detector, instruments that use these detectors cannot identify the type or energy of that radiation, or the specific radionuclide(s) present. The sensitivity can be improved by using headphones or the audible response during scans, or by integrating the exposure rate over time. The instrument has two primary limitations for environmental work. First, its minimum sensitivity is high, around 0.1 mR/hr in rate meter mode or 0.01 mR/hr in integrate mode. Some instruments use a large detector to improve low end sensitivity. However, in many instances the instrument is not sensitive enough for site survey work. Second, the detector's energy response is nonlinear. Energy compensated survey meters are commercially available, but the instrument's sensitivity may be reduced.

Cost of Equipment: $400 to $1,500.

Cost per Measurement: $5 per measurement for survey and report.

System: HAND-HELD ION CHAMBER SURVEY METER
Lab/Field: Field
Radiation Detected: **Primary:** Gamma **Secondary:** None

Applicability to Site Surveys: The hand-held ion chamber survey meter measures true gamma radiation exposure rate, in contrast to most other survey meter/probe combinations which are calibrated to measure exposure rate at one energy and approximate the exposure rate at all other energies. Due to their high detection limit, these instruments are not applicable for many final status surveys.

Operation: This device uses an ion chamber operated at a bias voltage sufficient to collect all ion pairs created by the passage of ionizing radiation, but not sufficiently high to generate secondary ion pairs as a proportional counter does. The units of readout are mR/hr, or some multiple of mR/hr. If equipped with an integrating mode, the operator can measure the total exposure over a period of time. The instrument may operate on two "D" cells or a 9 volt battery that will last for 100 to 200 hours of operation.

Specificity/Sensitivity: Ion chamber instruments respond only to gamma or x-radiation. They have no means to provide the identity of contaminants. Typical ion chamber instruments have a lower limit of detection of 0.5 mR/hr. These instruments can display readings below this, but the readings may be erratic and have large errors associated with them. In integrate mode, the instrument sensitivity can be as low as 0.05 mR/hr.

Cost of Equipment: $800 to $1,200

Cost per Measurement: $5, or higher for making integrated exposure measurements.

System: HAND-HELD PRESSURIZED ION CHAMBER (PIC) SURVEY METER

Lab/Field: Field

Radiation Detected: **Primary:** Gamma **Secondary:** None

Applicability to Site Surveys: The hand-held pressurized ion chamber survey meter measures true gamma radiation exposure rate, in contrast to most other survey meter/probe combinations which are calibrated to measure exposure rate at one energy and approximate the exposure rate at all other energies. Due to their high detection limit, these instruments are not applicable for many final status surveys.

Operation: This device uses a pressurized air ion chamber operated at a bias voltage sufficient to collect all ion pairs created by the passage of ionizing radiation, but not sufficiently high to cause secondary ionization.. The instrument is identical to the ion chamber meter on the previous page, except in this case the ion chamber is sealed and pressurized to 2 to 3 atmospheres to increase the sensitivity of the instrument by the same factors. The units of readout are μR/hr or mR/hr. A digital meter will allow an operator to integrate the total exposure over a period of time. The unit may use two "D" cells or a 9-volt battery that will last for 100 to 200 hours of operation.

Specificity/Sensitivity: Since the ion chamber is sealed, pressurized ion chamber instruments respond only to gamma or X-radiation. They have no means to provide the identity of contaminants. Typical instruments have a lower limit of detection of 0.1 mR/hr, or as low as 0.01 mR in integrate mode. These instruments can display readings below this, but the readings may be erratic and have large errors associated with them.

Cost of Equipment: $1,000 to $1,500

Cost per Measurement: $5, or higher for making integrated exposure measurements.

System: PORTABLE GERMANIUM MULTICHANNEL ANALYZER (MCA) SYSTEM
Lab/Field: Field
Radiation Detected: **Primary:** Gamma **Secondary:** None

Applicability for Site Surveys: This system produces semi-quantitative estimates of concentration of uranium and plutonium in soil, water, air filters, and quantitative estimates of many other gamma-emitting isotopes. With an appropriate dewar, the detector may be used in a vertical orientation to determine, *in situ*, gamma isotopes concentrations in soil.

Operation: This system consists of a portable germanium detector connected to a dewar of liquid nitrogen, high voltage power supply, and multichannel analyzer. It is used to identify and quantify gamma-emitting isotopes in soil or other surfaces.

Germanium is a semiconductor material. When a gamma ray interacts with a germanium crystal, it produces electron-hole pairs. An electric field is applied which causes the electrons to move in the conduction band and the holes to pass the charge from atom to neighboring atoms. The charge is collected rapidly and is proportional to the deposited energy.

The typical system consists of a portable multichannel analyzer (MCA) weighing about 7-10 lbs with batteries, a special portable low energy germanium detector with a built-in shield, and the acquisition control and spectrum analysis software. The detector is integrally mounted to a liquid nitrogen dewar. The liquid nitrogen is added 2-4 hours before use and replenished every 4-24 hours based on capacity.

The MCA includes all required front end electronics, such as a high voltage power supply, an amplifier, a digital stabilizer, and an analog-to-digital converter (ADC), which are fully controllable from a laptop computer and software.

One method uses the 94-104 keV peak region to analyze the plutonium isotopes from either "fresh" or aged materials. It requires virtually no user input or calibration. The source-to-detector distance for this method does not need to be calibrated as long as there are enough counts in the spectrum to perform the analysis.

For *in situ* applications, a collimated detector is positioned at a fixed distance from a surface to provide multichannel spectral data for a defined surface area. It is especially useful for qualitative and (based on careful field calibration or appropriate algorithms) quantitative analysis of freshly deposited contamination. Additionally, with prior knowledge of the depth distribution of the primary radionuclides of interest, which is usually not known, or using algorithms that match the site, the *in situ* system can be used to estimate the content of radionuclides distributed below the surface (dependent, of course, on adequate detection capability.)

Calibration based on Monte Carlo modeling of the assumed source-to-detector geometry or computation of fluence rates with analytical expressions is an important component to the accurate use of field spectrometry, when it is not feasible or desirable to use real radioactive sources. Such modeling used in conjunction with field spectrometry is becoming much more common recently, especially using the MCNP Monte Carlo computer software system.

Specificity/Sensitivity: With proper calibration or algorithms, field spectrometers can identify and quantify concentrations of gamma emitting radionuclides in the middle to upper energy range (*i.e.*, 50 keV with a P-type detector or 10 keV with an N-type detector).

For lower energy photons, as are important for plutonium and americium, an N-type detector or a planar crystal is preferred with a very thin beryllium (Be) window. This configuration allows measurement of photons in the energy range 5 to 80 keV. The Be window is quite fragile and a target of corrosion, and should be protected accordingly.

The detector high voltage should only be applied when the cryostat has contained sufficient liquid nitrogen for several hours. These systems can accurately identify plutonium, uranium, and many gamma-emitting isotopes in environmental media, even if a mixture of radionuclides is present. Germanium has an advantage over sodium iodide because it can produce a quantitative estimate of concentrations of multiple radionuclides in samples like soil, water, and air filters.

A specially designed low energy germanium detector that exhibits very little deterioration in the resolution as a function of count rate may be used to analyze uranium and plutonium, or other gamma-emitting radionuclides. When equipped with a built-in shield, it is unnecessary to build complicated shielding arrangements while making field measurements. Tin filters can be used to reduce the count rate from the ^{241}Am 59 keV line which allows the electronics to process more of the signal coming from Pu or U.

A plutonium content of 10 mg can be detected in a 55 gallon waste drum in about 30 minutes, although with high uncertainty. A uranium analysis can be performed for an enrichment range from depleted to 93% enrichment. The measurement time can be in the order of minutes depending on the enrichment and the attenuating materials.

Cost of Equipment: $40,000

Cost per Measurement: $100 to $200

System: PRESSURIZED IONIZATION CHAMBER (PIC)
Lab/Field: Field
Radiation Detected: **Primary:** Moderate (>80 keV) to high energy photons
Secondary: None

Applicability to Site Surveys: The PIC is a highly accurate ionization chamber for measuring gamma exposure rate in air, and for correcting for the energy dependence of other instruments due to their energy sensitivities. It is excellent for characterizing and evaluating the effectiveness of remediation of contaminated sites based on exposure rate. However, most sites also require nuclide-specific identification of the contributing radionuclides. Under these circumstances, PICs must be used in conjunction with other soil sampling or spectrometry techniques to evaluate the success of remediation efforts.

Operation: The PIC detector is a large sphere of compressed argon-nitrogen gas at 10 to 40 atmospheres pressure surrounded by a protective box. The detector is normally mounted on a tripod and positioned to sit about three feet off the ground. It is connected to an electronics box in which a strip chart recorder or digital integrator measures instantaneous and integrated exposure rate. It operates at a bias voltage sufficient to collect all ion pairs created by the passage of ionizing radiation, but not sufficiently high to amplify or increase the number of ion pairs . The high pressure inside the detector and the integrate feature make the PIC much more sensitive and precise than other ion chambers for measuring low exposures. The average exposure rate is calculated from the integrated exposure and the operating time. Arrays of PIC systems can be linked by telecommunications so their data can be observed from a central and remote location.

Specificity/Sensitivity: The PIC measures gamma or x-radiation and cosmic radiation. It is highly stable, relatively energy independent, and serves as an excellent tool to calibrate (in the field) other survey equipment to measure exposure rate. Since the PIC is normally uncollimated, it measures cosmic, terrestrial, and foreign source contributions without discrimination. Its rugged and stable behavior makes it an excellent choice for an unattended sensor where area monitors for gamma emitters are needed. PICs are highly sensitive, precise, and accurate to vast changes in exposure rate (1 μR/ hr up to 10 R/hr). PICs lack any ability to distinguish either energy spectral characteristics or source type. If sufficient background information is obtained , the data can be processed using algorithms that employ time and frequency domain analysis of the recorded systems to effectively separate terrestrial, cosmic, and "foreign" source contributions. One major advantage of PIC systems is that they can record exposure rate over ranges of 1 to 10,000,000 μR per hour (*i.e.*, μR/hr to 10 R/hr) with good precision and accuracy.

Cost of Equipment: $15,000 to $50,000 depending on the associated electronics, data processing, and telecommunications equipment.

Cost per Measurement: $50 to $500 based on the operating time at each site and the number of measurements performed.

System: SODIUM IODIDE SURVEY METER
Lab/Field: Field
Radiation Detected: **Primary:** Gamma **Secondary:** None
Applicability to Site Surveys: Sodium iodide survey meters can be response checked against a pressurized ionization chamber(PIC) and then used in its place so readings can be taken more quickly. This check should be performed often, possibly several times each day. They are useful for determining ambient radiation levels and for estimating the concentration of radioactive materials at a site.
Operation: The sodium iodide survey meter measures gamma radiation levels in μR/hr (10^{-6} R/hr) or counts per minute (cpm). Its response is energy and count rate dependent, so comparison with a pressurized ion chamber necessitates a conversion factor for adjusting the meter readings to true μR/hr values. The conversion factor obtained from this comparison is valid only in locations where the radionuclide mix is identical to that where the comparison is performed, and over a moderate range of readings. The detector is held at waist level or suspended near the surface and walked through an area listening to the audio and watching the display for changes. It is held in place and the response allowed to stabilize before each measurement is taken, with longer times required for lower responses. Generally, the center of the needle swing or the integrated reading is recorded. The detector is a sodium iodide crystal inside an aluminum container with an optical glass window that is connected to a photomultiplier tube. A gamma ray that interacts with the crystal produces light that travels out of the crystal and into the photomultiplier tube. There, electrons are produced and multiplied to produce a readily measurable pulse whose magnitude is proportional to the energy the gamma ray incident on the crystal. Electronic filters accept the pulse as a count if certain discrimination height restrictions are met. This translates into a meter response. Instruments with pulse height discrimination circuitry can be calibrated to view the primary gamma decay energy of a particular isotope. If laboratory analysis has shown a particular isotope to be present, the discrimination circuitry can be adjusted to partially tune out other isotopes, but this also limits its ability to measure exposure rate.
Specificity/Sensitivity: Sodium iodide survey meters measure gamma radiation in μR/hr or cpm with a minimum sensitivity of around 1-5 μR per hour, or 200-1,000 cpm, or lower in digital integrate mode. The reading error of 50% can occur at low count rates because of a large needle swing, but this decreases with increased count rate. The instrument is quite energy sensitive, with the greatest response around 100-120 keV and decreasing in either direction. Measuring the radiation level at a location with both a PIC and the survey meter gives a factor for converting subsequent readings to actual exposure rates. This ratio can change with location. Some meters have circuitry that looks at a few selected ranges of gamma energies, or one at a time with the aide of a single channel analyzer. This feature is used to determine if a particular isotope is present. The detector should be protected against thermal or mechanical shock which can break the sodium iodide crystal or the photomultiplier tube. Covering at least the crystal end with padding is often sufficient. The detector is heavy, so adding a carrying strap to the meter and a means of easily attaching and detaching the detector from the meter case helps the user endure long surveys.
Cost of Equipment: $2,000
Cost per Measurement: $5

System: THERMOLUMINESCENCE DOSIMETER (TLD)
Lab/Field: Field and lab
Radiation Detected: **Primary:** Gamma **Secondary:** Neutron, beta, x-ray
Applicability to Site Surveys: TLDs can be used to measure such a low dose equivalent that they can identify gamma levels slightly above natural background. TLDs should be placed in areas outside the site but over similar media to determine the average natural background radiation level in the area. Other TLDs should be posted on site to determine the difference from background. Groups should be posted quarterly for days to quarters and compared to identify locations of increased onsite doses.
Operation: A TLD is a crystal that measures radiation dose. TLDs are semiconductor crystals that contain small amounts of added impurities. When radiation interacts with the crystal, electrons in the valence band are excited into the conduction band. Many lose their energy and return directly to the valence band, but some are trapped at an elevated energy state by the impurity atoms. This trapped energy can be stored for long periods, but the signal can fade with age, temperature, and light. Heating the TLD in a TLD reader releases the excess energy in the form of heat and light. The quantity or intensity of the light given off gives a measure of the radiation dose the TLD received. If the TLDs are processed at an off site location, the transit dose (from the location to the site and return) must be determined and subtracted from the net dose. The ability to determine this transit dose affects the net sensitivity of the measurements. The TLD is left in the field for a period of a day to a quarter and then removed from the field and read in the laboratory on a calibrated TLD reader. The reading is the total dose received by the TLD during the posting period. TLDs come in various shapes (thin-rectangles, rods, and powder), sizes (0.08 cm to 0.6 cm (1/32 in. to 1/4 in.) on a side), and materials (CaF_2:Mn, $CaSO_4$:Dy, ^{6}LiF:Mn, ^{7}LiF:Mn, $LiBO_4$, LiF:Mg,Cu,P and Al_2O_3:C). The TLD crystals can be held loosely inside a holder, sandwiched between layers of Teflon, affixed to a substrate, or attached to a heater strip and surrounded by a glass envelope. Most are surrounded by special thin shields to correct for an over response to low-energy radiation. Many have special radiation filters to allow the same type TLD to measure various types and energies of radiation.
Specificity/Sensitivity: TLDs are primarily sensitive to gamma radiation, but selected TLD/filter arrangements can be used to measure beta, x-ray, and neutron radiation. They are posted both on site and off site in comparable areas. These readings are compared to determine if the site can cause personnel to receive more radiation exposure than would be received from background radiation. The low-end sensitivity can be reduced by specially calibrating each TLD and selecting those with high accuracy and good precision. The new Al_2O_3 TLD may be capable of measuring doses as low as 0.1 μSv (0.01 mrem) while specially calibrated CaF_2 TLDs posted quarterly can measure dose differences as low as 0.05 mSv/y (5 mrem/y). This is in contrast to standard TLDs that are posted monthly and may not measure doses below 1 mSv/y (100 mrem/y). TLDs should be protected from damage as the manufacturer recommends. Some are sensitive to visible light, direct sunlight, fluorescent light, excessive heat, or high humidity.
Cost of Equipment: $5K-$ 100K (reader), $25-$40 (TLD). TLDs cost $5 to $40 per rental.
Cost per Measurement: $25 to $125

H.2 FIELD SURVEY EQUIPMENT

H.2.4 Radon Detectors

System: ACTIVATED CHARCOAL ADSORPTION
Lab/Field: Field
Radiation Detected: **Primary:** Radon gas **Secondary:** None

Applicability to Site Surveys: Activated charcoal adsorption is a passive low cost screening method for measuring indoor air radon concentration. The charcoal adsorption method is not designed for outdoor measurements. For contaminated structures, charcoal is a good short-term indicator of radon contamination. Vendors provide measurement services which includes the detector and subsequent readout.

Operation: For this method, an airtight container with activated charcoal is opened in the area to be sampled and radon in the air adsorbs onto the charcoal. The detector, depending on its design, is deployed for 2 to 7 days. At the end of the sampling period, the container is sealed and sent to a laboratory for analysis. Proper deployment and analysis will yield accurate results.

Two analysis methods are commonly used in activated charcoal adsorption. The first method calculates the radon concentration based on the gamma decay from the radon progeny analyzed on a gamma scintillation or semiconductor detection system. The second method is liquid scintillation which employs a small vial containing activated charcoal for sampling. After exposure, scintillation fluid is added to the vial and the radon concentration is determined by the alpha and beta decay of the radon and progeny when counted in a liquid scintillation spectrometer.

Specificity/Sensitivity: Charcoal absorbers are designed to measure radon concentrations in indoor air. Some charcoal absorbers are sensitive to drafts, temperature and humidity. However, the use of a diffusion barrier over the charcoal reduces these effects. The minimum detectable concentration for this method ranges from 0.007-0.04 Bq/L (0.2-1.0 pCi/L).

Cost of Equipment: $10,000 for a liquid scintillation counter, $10,000 for a sodium iodide multichannel analyzer system, or $30,000+ for a germanium multichannel analyzer system. The cost of the activated charcoal itself is minimal.

Cost per Measurement: $5 to $30 including canister.

System: ALPHA TRACK DETECTOR
Lab/Field: Field
Radiation Detected: **Primary:** Radon Gas (Alpha Particles) **Secondary:** None
Applicability to Site Surveys: An alpha track detector is a passive, low cost, long term method used for measuring radon. Alpha track detectors can be used for site assessments both indoors and outdoors (with adequate protection from the elements).

Operation: Alpha track detectors employ a small piece of special plastic or film inside a small container. Air being tested diffuses through a filtering mechanism into the container. When alpha particles from the decay of radon and its progeny strike the detector, they cause damage tracks. At the end of exposure, the container is sealed and returned to the laboratory for analysis.

The plastic or film detector is chemically treated to amplify the damage tracks and then the number of tracks over a predetermined area are counted using a microscope, optical reader, or spark counter. The radon concentration is determined by the number of tracks per unit area. Detectors are usually exposed for 3 to 12 months, although shorter time frames may be used when measuring high radon concentrations.

Specificity/Sensitivity: Alpha track detectors are primarily used for indoor air measurements but specially designed detectors are available for outdoor measurements. Alpha track results are usually expressed as the radon concentration over the exposure period (Bq/L-days). The sensitivity is a function of detector design and exposure duration, and is on the order of 0.04 Bq/L-day (1 pCi/L-day).

Cost of Equipment: Not applicable when provided by a vendor

Cost per Measurement: $5 to $25

System: CONTINUOUS RADON MONITOR
Lab/Field: Field
Radiation Detected: **Primary:** Radon gas **Secondary:** None

Applicability to Site Surveys: Continuous radon monitors are devices that measure and record real-time measurements of radon gas or variations in radon concentration on an hourly basis. Since continuous monitors display real-time hourly radon measurements, they are useful for short-term site investigation.

Operation: Continuous radon monitors are precision devices that track and record real-time measurements and variations in radon gas concentration on an hourly basis. Air either diffuses or is pumped into a counting chamber. The counting chamber is typically a scintillation cell or ionization chamber. Using a calibration factor, the counts are processed electronically, and radon concentrations for predetermined intervals are stored in memory or directly transmitted to a printer.

Most continuous monitors are used for a relatively short measurement period, usually 1 to 7 days. These devices do require some operator skills and often have a ramp-up period to equilibrate with the surrounding atmosphere. This ramp-up time can range from 1 to 4 hours depending on the size of the counting chamber and rate of air movement into the chamber.

Specificity/Sensitivity: Most continuous monitors are designed for both indoor and outdoor radon measurements. The limiting factor for outdoor usage is the need for electrical power. In locations where external power is unavailable, the available operating time depends on the battery lifetime of the monitor. The minimum detectable concentration for these detectors ranges from 0.004-0.04 Bq/L (0.1-1.0 pCi/L).

Cost of Equipment: $1,000 to $5,000.

Cost per Measurement: $80+ based on duration of survey.

System: ELECTRET ION CHAMBER
Lab/Field: Field
Radiation Detected: **Primary:** Radon gas (alpha, beta) **Secondary:** Gamma

Applicability to Site Surveys: Electrets are used to measure radon concentration in indoor environments. For contaminated structures, the electret ion chamber is a good indicator of short-term and long-term radon concentrations.

Operation: For this method, an electrostatically charged disk (electret) is situated within a small container (ion chamber). During the measurement period, radon diffuses through a filter into the ion chamber, where the ionization produced by the decay of radon and its progeny reduces the charge on the electret. A calibration factor relates the voltage drop, due to the charge reduction, to the radon concentration. Variations in electret design enable the detector to make long-term or short-term measurements. Short-term detectors are deployed for 2 to 7 days, whereas long-term detectors may be deployed from 1 to 12 months.

Electrets are relatively inexpensive, passive, and can be used several times before discarding or recharging, except in areas of extreme radon concentrations. These detectors need to be corrected for the background gamma radiation during exposure since this ionization also discharges the electret.

Specificity/Sensitivity: Electrets are designed to make radon measurements primarily in indoor environments. Care must be taken to measure the background gamma radiation at the site during the exposure period. Extreme temperatures and humidity encountered outdoors may affect electret voltage. The minimum detectable concentration ranges from 0.007-0.02 Bq/L (0.2 to 0.5 pCi/L).

Cost of Equipment: Included in rental price

Cost per Measurement: $8 to $25 rental for an electret supplied by a vendor

System: LARGE AREA ACTIVATED CHARCOAL COLLECTOR
Lab/Field: Field
Radiation Detected: **Primary:** Radon gas **Secondary:** None

Applicability to Site Surveys: This method is used to make radon flux measurements (the surface emanation rate of radon gas) and involves the adsorption of radon on activated carbon in a large area collector.

Operation: The collector consists of a 10 inch diameter PVC end cap, spacer pads, charcoal distribution grid, retainer pad with screen, and a steel retainer spring. Between 170 and 200 grams of activated charcoal is spread in the distribution grid and held in place by the retainer pad and spring.

The collector is deployed by firmly twisting the end cap into the surface of the material to be measured. After 24 hours of exposure, the activated charcoal is removed and transferred to plastic containers. The amount of radon adsorbed on the activated charcoal is determined by gamma spectroscopy. This data is used to calculate the radon flux in units of Bq m^{-2} s^{-1}.

Specificity/Sensitivity: These collectors give an accurate short-term assessment of the radon gas surface emanation rate from a material. The minimum detectable concentration of this method is 0.007 Bq m^{-2} s^{-1} (0.2 pCi m^{-2} s^{-1}).

Exposures greater than 24 hours are not recommended due to atmospheric and surface moisture and temperature extremes which may affect charcoal efficiency.

Cost of Equipment: Not applicable

Cost per Measurement: $20 - $50 including canister

H.2 FIELD SURVEY EQUIPMENT

H.2.5 X-Ray and Low Energy Gamma Detectors

System: FIDLER PROBE WITH SURVEY METER
Lab/Field: Field
Radiation Detected: **Primary:** X-ray **Secondary:** Low Energy Gamma
Applicability to Site Surveys: The FIDLER (Field Instrument for the Detection of Low Energy Radiation) probe is a specialized detector consisting of a thin layer of sodium or cesium iodide which is optimized to detect gamma and x-radiation below 100 keV. It is most widely used for determining the presence of Pu and ^{241}Am, and can be used for estimating radionuclide concentrations in the field.
Operation: The FIDLER consists of a thin beryllium or aluminum window, a thin crystal of sodium iodide, a quartz light pipe, and photomultiplier tube. The probe can have either a 3 in. or 5 in. crystal. The discussion below is applicable to 5 in. crystals. The survey meter requires electronics capable of setting a window about an x-ray or gamma ray energy. This window allows the probe and meter to detect specific energies and, in most cases, provide information about a single element or radionuclide. The window also lowers the background count. Two types of survey meters are generally used with FIDLER probes. One type resembles those used with GM and alpha scintillation probes. They have an analog meter and range switch. The second type is a digital survey meter, which can display the count rate or accumulate counts in a scaler mode for a preset length of time. Both types have adjustable high voltage and window settings. The advantage of the digital meter is that both background and sample counts can be acquired in scaler mode, yielding a net count above background. The activity of a radionuclide can then be estimated in the field.
Specificity/Sensitivity: The FIDLER probe is quite sensitive to x-ray and low energy gamma radiation. Since it has the ability to discriminate energies, an energy window can be set that makes it possible to determine the presence of specific radionuclides when the nature of the contamination is known. If the identity of a contaminant is known, the FIDLER can be used to quantitatively determine the concentration. However, interferences can cause erroneous results if other radionuclides are present. The FIDLER can also be used as a survey instrument to detect the presence of x-ray or low energy gamma contaminates, and to determine the extent of the contamination. FIDLER probes are most useful for determining the presence of Pu and ^{241}Am. These isotopes have a complex of x-rays and gamma rays from 13-21 keV that have energies centered around 17 keV, and ^{241}Am has a gamma at 59 keV. There is an interference at 13 keV from both americium and uranium x-rays. The FIDLER cannot distinguish which isotope of Pu is present. ^{241}Am can be identified based on the 59 keV gamma. Typical sensitivities for ^{238}Pu and ^{239}Pu at one foot above the surface of a contaminated area are 500 to 700 and 250 to 350 counts per minute per μCi per square meter (cpm/μCi/m^2), respectively. Assuming a soil density of 1.5, uniform contamination of the first 1 mm of soil, and a typical background of 400 counts per minute, the MDC for ^{238}Pu and ^{239}Pu would be 370 and 740 Bq/kg (10 and 20 pCi/g), or 1500 and 3000 Bq/m^2 (900 and 1,800 dpm/100 cm^2). This MDC is for fresh deposition; and will be significantly less as the plutonium migrates into the soil. Because the window is fragile, most operations with a FIDLER probe require a low mass protective cover to prevent damaging the window. Styrofoam, cardboard, and other cushioning materials are common choices for a protective cover.
Cost of Equipment: $4,000 to $7,000
Cost per Measurement: $10 to $20

System: FIELD X-RAY FLUORESCENCE SPECTROMETER
Lab/Field: Field
Radiation Detected: **Primary:** X-ray and low energy gamma radiation
Secondary: None

Applicability to Site Surveys: The system accurately measures relative concentrations of metal atoms in soil or water samples down to the ppm range.

Operation: This system is a rugged form of x-ray fluorescence system that measures the characteristic x-rays of metals as they are released from excited electron structures. The associated electronic and multi-channel analyzer systems are essentially identical to those used with germanium spectrometry systems. The spectra of characteristic x-rays gives information for both quantitative and qualitative analysis; however, most frequently, the systems are only calibrated for relative atomic abundance or percent composition.

Specificity/Sensitivity: This is ideal for cases of contamination by metals that have strong x-ray emissions within 5-100 keV. Application for quantification of the transition metals (in the periodic table) is most common because of the x-ray emissions. Operation of this equipment is possible with only a moderate amount of training. The sensitivity ranges from a few percent to ppm depending on the particular atoms and their characteristic x-rays. When converted to activity concentration, the minimum detectable concentration for ^{238}U is around 1,850 Bq/kg (50 pCi/g) for typical soil matrices.

Cost of Equipment: $15,000 - $75,000 depending on size, speed of operation and auxiliary features employed for automatic analysis of the results.

Cost per Measurement: $200

H.2 FIELD SURVEY EQUIPMENT

H.2.6 Other Field Survey Equipment

System: CHEMICAL SPECIES LASER ABLATION MASS SPECTROMETER
Lab/Field: Field
Radiation Detected: None

Applicability to Site Surveys: Chemical Species Laser Ablation Mass Spectrometry has been successfully applied to the analysis of organic and inorganic molecular species in condensed material with high sensitivity and specificity.

Operation: Solids can be converted into aerosol particles which contain much of the molecular species information present in the original material. (One way this is done is by laser excitation of one component of a solid mixture which, when volatilized, carries along the other molecular species without fragmentation.) Aerosol particles can be carried hundreds of feet without significant loss in a confined or directed air stream before analysis by mass spectrometry. Some analytes of interest already exist in the form of aerosol particles. Laser ablation is also preferred over traditional means for the conversion of the aerosol particles into molecular ions for mass spectral analysis. Instrument manufacturers are working with scientists at national laboratories and universities in the development of compact portable laser ablation mass spectrometry instrumentation for field based analyses.

Specificity/Sensitivity: This system can analyze soils and surfaces for organic and inorganic molecular species, with extremely good sensitivity. Environmental concentrations in the range of 10^{-9} - 10^{-14} g/g can be determined, depending on environmental conditions. It is highly effective when used by a skilled operator, but of limited use due to high costs. It may be possible to quantify an individual radionuclide if no other nuclides of that isotope are present in the sample matrix. Potential MDC's are $4x10^{-8}$ Bq/kg ($1x10^{-9}$ pCi/g) for ^{238}U, 0.04 Bq/kg (10^{-3} pCi/g) for ^{239}Pu, 4 Bq/kg (1 pCi/g) for ^{137}Cs, and 37 Bq/kg (10 pCi/g) for ^{60}Co.

Cost of Equipment: Very expensive (prototype)

Cost per Measurement: May be comparable to laser ablation inductively coupled plasma atomic emission spectrometry (LA-ICP-AES) and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). When using the Atomic Emission Spectrometer, the reported cost is $4,000 per sample, or 80% of conventional sampling and analysis costs. This high cost for conventional samples is partly due to the 2-3 day time to analyze a sample for thorium by conventional methods. When using the mass spectrometer, the time required is about 30 minutes per sample.

System: LA-ICP-AES AND LA-ICP-MS
Lab/Field: Field
Radiation Detected: None

Applicability to Site Surveys: LA-ICP-AES and LA-ICP-MS are acronyms for Laser Ablation-Inductively Coupled Plasma-Atomic Emission Spectrometry or Mass Spectrometry. LA-ICP-AES/MS techniques are used to screen/characterize very small samples of soils and concrete (non-destructively) *in situ* to determine the level of contamination. It is particularly suited to measuring the surface concentration of uranium and thorium. The unit can assess the concentrations at various depths when lower levels are exposed by some means. It has the advantages of not consuming surface material, providing real time response, reducing sampling and analysis time, and keeping personnel clear of the materials being sampled. The information developed can assist in identifying locations for excavation. It is currently being tested.

Operation: Components of the system include a sampling system, fiber optics cables, spectrometer, potable water supply, cryogenic and high-pressure gas supply, a robotics arm, control computers, inductively coupled plasma torch, and video monitor.

Sampling probes have been developed and prototyped that will screen/characterize surface soils, concrete floors or pads, and subsurface soils. The sampling probes, both surface and subsurface, contain the laser (a 50-Hz Nd/YAG laser), associated optics, and control circuitry to raster the laser (ablation) energy across one square inch of sample surface. Either sampling probe is connected by an umbilical, currently 20 m long, to the Mobile Demonstration Laboratory for Environmental Screening Technologies (MDLEST), a completely self-contained mobile laboratory containing the instrumentation to immediately analyze the samples generated by the laser ablation.

A fiber optic cable delivers laser light to the surface of interest. This ablates a small quantity of material that is carried away in a stream of argon gas. The material enters the plasma torch where it is vaporized, atomized, ionized, and electrically excited at about 8,000 K. This produces an ionic emission spectrum that is analyzed on the atomic emission spectrometer.

The analysis instrumentation (ICP-AES/MS) in the MDLEST does not depend on radioactive decay for detection but looks directly at the atomic make up of the elements(s) of interest. A large number of metals including the longer half-life radioactive elements can be detected and quantified. The spectrometer is set up using either hardware, software, or both to simultaneously detect all elements of interest in each sample.

The MDLEST can be set up on site to monitor soil treatment processes. This function enables the remediation manager to monitor, in real time, the treatment processes removing the contaminants and ensure that satisfactory agreement with both regulatory agency and QC/QA requirements is attained.

Specificity/Sensitivity: This system measures the surface or depth concentration of atomic species, and is particularly suited to uranium and thorium analysis. It is highly effective with skilled operators. Some advantages are no contact with the soil, real time results, and no samples to dispose of. The sample results are quickly available for field remediation decisions, with the LA-ICP-AES taking about 10 minutes and LA-ICP-MS taking about 30 minutes. The detection limits for the two spectrometers that have been used are as follows:

1) The AES (atomic emission spectrometer) can see ppm levels for some 70 elements and reportedly detects uranium and thorium concentrations at 1 ppm, or 10 Bq/kg (0.3 pCi/g) for ^{238}U and 0.4 Bq/kg (0.1 pCi/g) for ^{232}Th. However, the technique is only sensitive to elements; it cannot discriminate between the different isotopes of uranium and thorium. This prevents it from being used for assessing lower Z elements that have stable isotopes, or from determining relative abundances of isotopes of any element. This may significantly limit its use at some sites.
2) The MS (mass spectrometer) can see sub-ppb levels and is capable of quantifying the uranium and thorium isotopes. This system has been used to search for ^{230}Th and ^{226}Ra and is reportedly useful in reaching 0.8 ppm or 0.6 Bq/g (15 pCi/g) for ^{230}Th content for remediated soil. It appears to measure uranium and thorium concentration of soil more sensitively than the LA-ICP-AES system.

Cost of Equipment: Very expensive, >$1M.

Cost per Measurement: When using the Atomic Emission Spectrometer, the reported cost is $4,000 per sample. When using the mass spectrometer, a dollar price was not provided.

H.3 LABORATORY INSTRUMENTS

H.3.1 Alpha Particle Analysis

System: ALPHA SPECTROSCOPY WITH MULTICHANNEL ANALYZER
Lab/Field: Lab
Radiation Detected: **Primary:** Alpha **Secondary:** None
Applicability to Site: This is a very powerful tool for accurately identifying and quantifying the activity of multiple alpha-emitting radionuclides in a sample of soil, water, air filters, etc. Methods exist for the analyses of most alpha emitting radionuclides including uranium, thorium, plutonium, polonium, and americium. Samples must first be prepared in a chemistry lab to isolate the radionuclides of interest from the environmental matrix.
Operation: This system consists of an alpha detector housed in a light-tight vacuum chamber, a bias supply, amplifier, analog-to-digital converter, multichannel analyzer, and computer. The bias is typically 25 to 100 volts. The vacuum is typically less than 10 microns (0.1 millitorr). The detector is a silicon diode that is reverse biased. Alpha particles which strike the diode create electron-hole pairs; the number of pairs is directly related to the energy of each alpha. These pairs cause a breakdown of the diode and a current pulse to flow. The charge is collected by a preamplifier and converted to a voltage pulse which is proportional to the alpha energy. It is amplified and shaped by an amplifier. The MCA stores the resultant pulses and displays a histogram of the number of counts vs. alpha energy. Since most alphas will loose all of their energy to the diode, peaks are seen on the MCA display that can be identified by specific alpha energies. Two system calibrations are necessary. A source with at least two known alpha energies is counted to correlate the voltage pulses with alpha energy. A standard source of known activity is analyzed to determine the system efficiency for detecting alphas. Since the sample and detector are in a vacuum, most commonly encountered alpha energies will be detected with approximately the same efficiency, provided there is no self-absorption in the sample. Samples are prepared in a chemistry lab. The sample is placed in solution and the element of interest (uranium, plutonium, *etc.*) separated. A tracer of known activity is added before separation to determine the overall recovery of the sample from the chemical procedures. The sample is converted to a particulate having very little mass and collected on a special filter, or it is collected from solution by electroplating onto a metal disk. It is then placed in the vacuum chamber at a fixed distance from the diode and analyzed. For environmental levels, samples are typically analyzed for 1000 minutes or more.
Specificity/Sensitivity: The system can accurately identify and quantify the various alpha emitting radioactive isotopes of each elemental species provided each has a different alpha energy that can be resolved by the system. For soils, a radionuclide can be measured below 0.004 Bq/g (0.1 pCi/g) . The system is appropriate for all alphas except those from gaseous radionuclides.
Cost of Equipment: $10,000 - $100,000 based on the number of detectors and sophistication of the computer and data reduction software. This does not include the cost of equipment for the chemistry lab.
Cost per Measurement: $250-$400 for the first element, $100-200 for each additional element per sample. The additional element cost depends on the separation chemistry involved and may not always be less. $200-$300 additional for a rush analysis.

System: GAS-FLOW PROPORTIONAL COUNTER
Lab/Field: Lab
Radiation Detected: **Primary:** Alpha, Beta **Secondary:** Gamma
Applicability to Site Surveys: This system can determine the gross alpha or gross beta activity of water, soil, air filters, or swipes. Results can indicate if nuclide-specific analysis is needed.
Operation: The system consists of a gas-flow detector, supporting electronics, and an optional guard detector for reducing background count rate. A thin window can be placed between the gas-flow detector and sample to protect the detector from contamination, or the sample can be placed directly into the detector. Systems with guard detectors operate sample and guard detectors in anticoincidence mode to reduce the background and MDC. The detector high voltage and discriminator are set to count alpha radiation, beta radiation, or both simultaneously. The alpha and beta operating voltages are determined for each system by placing an alpha source, like ^{230}Th or ^{241}Am, in the detector and increasing the high voltage incrementally until the count rate becomes constant, then repeating with a beta source, like ^{90}Sr. The alpha plateau, or region of constant count rate, should have a slope <2%/100V and be >800V long. The beta plateau should have a slope of <2.5%/100V and be >200V long. Operation on the beta plateau will also allow detection of some gamma radiation and bremsstrahlung (x-rays), but the efficiency is very low. Crosstalk between the α-to-β channels is typically around 10% while β-to-α channels should be <1%. The activity in soil samples is chemically extracted, separated if necessary, deposited in a thin layer in a planchet to minimize self absorption, and heated to dryness. Liquids are deposited and dried, while air filters and swipes are placed directly in the planchet. After each sample is placed under the detector, P-10 counting gas constantly flows through the detector. Systems with automatic sample changers can analyze tens to hundreds of planchet samples in a single run.
Specificity/Sensitivity: Natural radionuclides present in soil samples can interfere with the detection of other contaminants. Unless the nature of the contaminant and any naturally-occurring radionuclides is well known, this system is better used for screening samples. Although it is possible to use a proportional counter to roughly determine the energies of alpha and beta radiation, the normal mode of operation is to detect all alpha events or all alpha and beta events. Some systems use a discriminator to separate alpha and beta events, allowing simultaneous determination of both the alpha and beta activity in a sample. These systems do not identify the alpha or beta energies detected and cannot be used to identify specific radionuclides. The alpha channel background is very low, <0.2 cpm (<0.04 cpm guarded), depending on detector size. Typical, 4-pi, efficiencies for very thin alpha sources are 35-45% (window) and 40-50% (windowless). Efficiency depends on window thickness, particle energy, source-detector geometry, backscatter from the sample and holder, and detector size. The beta channel background ranges from 2 to 15 cpm (<0.5 cpm guarded). The 4-pi efficiency for a thin ^{90}Sr/^{90}Y source is >50% (window) to >60% (windowless), but can reduce to <5% for a thick source. MDA's for guarded gas-flow proportional counters are somewhat lower for beta emitters than for internal proportional counters because of the lower backgrounds. Analyzing a high radioactivity sample or flushing the detector with P10 gas at too high a flow rate can suspend fine particles and contaminate the detector.
Cost of Equipment: $4K-$5K (manual), $25K-$30K (automatic)
Cost per Measurement: $30 to $50 plus radiochemistry

System: LIQUID SCINTILLATION SPECTROMETER
Lab/Field: Lab (primarily), field (secondarily)
Radiation Detected: **Primary:** Alpha, beta **Secondary:** Gamma
Applicability to Site Surveys: Liquid Scintillation can be a very effective tool for measuring the concentration of radionuclides in soil, water, air filters, and swipes. Liquid scintillation has historically been applied more to beta emitters, particularly the low energy beta emitters ^{3}H and ^{14}C, but it can also apply to other radionuclides. More recently it has been used for measuring radon in air and water. Initial scoping surveys may be done (particularly for loose surface contamination) with surface swipes or air particulate filters. They may be counted directly in liquid scintillation cocktails with no paper dissolution or other sample preparation.
Operation: The liquid scintillation process involves detection of light pulses (usually in the near visible range) by photo-multiplier tubes (or conceptually similar devices). The detected light pulses originate from the re-structuring of previously excited molecular electron structures. The molecular species that first absorb and then re-admit the visible light are called "liquid scintillators" and the solutions in which they reside are called "liquid scintillation cocktails." For gross counting, samples may be placed directly into a LSC vial of cocktail, and counted with no preparation. Inaccuracies result when the sample itself absorbs the radiation before it can reach the LSC cocktail, or when the sample absorbs the light produced by the cocktail. For accurate results, these interferences are minimized. Interferences in liquid scintillation counting due to the inability of the solution to deliver the full energy pulse to the photo-multiplier detector, for a variety of reasons, are called "pulse quenching." Raw samples that cloud or color the LSC cocktail so the resulting scintillations are absorbed will "quench" the sample and result in underestimates of the activity. Such samples are first processed by ashing, radiochemical or solvent extraction, or pulverizing to place the sample in intimate contact with the LSC cocktail. Actions like bleaching the sample may also be necessary to make the cocktail solution transparent to the wavelength of light it emits. The analyst has several reliable computational or experimental procedures to account for "quenching." One is by exposing the sample and pure cocktail to an external radioactive standard and measuring the difference in response.
Specificity/Sensitivity: The method is extremely flexible and accurate when used with proper calibration and compensation for quenching effects. Energy spectra are 10 to 100 times broader than gamma spectrum photopeaks so that quantitative determination of complex multi-energy beta spectra is impossible. Sample preparation can range from none to complex chemical reactions. In some cases, liquid scintillation offers many unique advantages; no sample preparation before counting in contrast to conventional sample preparation for gas proportional counting. Recent advances in electronic stability and energy pulse shape discrimination has greatly expanded uses. Liquid scintillation counters are ideal instruments for moderate to high energy beta as well as alpha emitters, where the use of pulse shape discrimination has allowed dramatic increases in sensitivity by electronic discrimination against beta and gamma emitters. Additionally, very high energy beta emitters (above 1.5 MeV) may be counted using liquid scintillation equipment without "liquid scintillation cocktails" by use of the Cerenkov light pulse emitted as high energy charged particles move through water or similar substances.
Cost of Equipment: $20,000 to $70,000 based on the specific features and degree of automation
Cost per Measurement: $50 -200 plus cost of chemical separation, if required

System: LOW-RESOLUTION ALPHA SPECTROSCOPY
Lab/Field: Lab (Soil Samples)
Radiation Detected: **Primary:** Alpha **Secondary:**

Applicability to Site Surveys: Low-resolution alpha spectroscopy is a method for measuring alpha activity in soils with a minimum of sample preparation. Some isotopic information can be obtained.

Operation: The system consists of a 2 in. diameter silicon detector, small vacuum chamber, roughing pump, multichannel analyzer, laptop or benchtop computer, and analysis software. Soil samples are dried, milled to improve homogeneity, distributed into 2 in. planchets, loaded into the vacuum chamber, and counted. The accumulated alpha spectrum is displayed in real time. When sufficient counts have been accumulated, the spectrum is transferred to a data file and the operator inputs the known or suspected contaminant isotopes. The analysis software then fits the alpha spectrum with a set of trapezoidal peaks, one for each isotope, and outputs an estimate of the specific activity of each isotope.

Specificity/Sensitivity: This method fills the gap between gross alpha analysis and radiochemical separation/high-resolution alpha spectroscopy. Unlike gross alpha analysis, it does provide some isotopic information. Because this is a low-resolution technique, isotopes with energies closer than ~0.2 MeV cannot be separated. For example, ^{238}U (4.20 MeV) can be readily distinguished from ^{234}U (4.78 MeV), but ^{230}Th (4.69 MeV) cannot be distinguished from ^{234}U.

Because no chemical separation of isotopes is involved, only modest MDC's can be achieved. Detection limits are determined by the background alpha activity in the region of interest of the contaminant of concern, and also by the counting time. Typical MDC's are 1,500 Bq/kg (40 pCi/g) @ 15 min counting time, 260 Bq/kg (7 pCi/g) @ 8 hours, and 185 Bq/kg (5 pCi/g) @ 24 hours. The method does not generate any new waste streams and does not require a sophisticated laboratory or highly-trained personnel.

Cost of Equipment: $11,000

Cost per Measurement: $25-$100

H.3 LABORATORY INSTRUMENTS

H.3.2 Beta Particle Analysis

System: GAS-FLOW PROPORTIONAL COUNTER
Lab/Field: Lab
Radiation Detected: **Primary:** Alpha, Beta **Secondary:** Gamma
Applicability to Site Surveys: This system can determine the gross alpha or gross beta activity of water, soil, air filters, or swipes. Results can indicate if nuclide-specific analysis is needed.
Operation: The system consists of a gas-flow detector, supporting electronics, and an optional guard detector for reducing background count rate. A thin window can be placed between the gas-flow detector and sample to protect the detector from contamination, or the sample can be placed directly into the detector. Systems with guard detectors operate sample and guard detectors in anticoincidence mode to reduce the background and MDC. The detector high voltage and discriminator are set to count alpha radiation, beta radiation, or both simultaneously. The alpha and beta operating voltages are determined for each system by placing an alpha source, like ^{230}Th or ^{241}Am, in the detector and increasing the high voltage incrementally until the count rate becomes constant, then repeating with a beta source, like ^{90}Sr. The alpha plateau, or region of constant count rate, should have a slope <2%/100V and be >800V long. The beta plateau should have a slope of <2.5%/100V and be >200V long. Operation on the beta plateau will also allow detection of some gamma radiation and bremsstrahlung (x-rays), but the efficiency is very low. Crosstalk between the α-to-β channels is typically around 10% while β-to-α channels should be <1%. The activity in soil samples is chemically extracted, separated if necessary, deposited in a thin layer in a planchet to minimize self absorption, and heated to dryness. Liquids are deposited and dried, while air filters and swipes are placed directly in the planchet. After each sample is placed under the detector, P-10 counting gas constantly flows through the detector. Systems with automatic sample changers can analyze tens to hundreds of planchet samples in a single run.
Specificity/Sensitivity: Natural radionuclides present in soil samples can interfere with the detection of other contaminants. Unless the nature of the contaminant and any naturally-occurring radionuclides is well known, this system is better used for screening samples. Although it is possible to use a proportional counter to roughly determine the energies of alpha and beta radiation, the normal mode of operation is to detect all alpha events or all alpha and beta events. Some systems use a discriminator to separate alpha and beta events, allowing simultaneous determination of both the alpha and beta activity in a sample. These systems do not identify the alpha or beta energies detected and cannot be used to identify specific radionuclides. The alpha channel background is very low, <0.2 cpm (<0.04 cpm guarded), depending on detector size. Typical, 4-pi, efficiencies for very thin alpha sources are 35-45% (window) and 40-50% (windowless). Efficiency depends on window thickness, particle energy, source-detector geometry, backscatter from the sample and holder, and detector size. The beta channel background ranges from 2 to 15 cpm (<0.5 cpm guarded). The 4-pi efficiency for a thin ^{90}Sr/^{90}Y source is >50% (window) to >60% (windowless), but can reduce to <5% for a thick source. MDA's for guarded gas-flow proportional counters are somewhat lower for beta emitters than for internal proportional counters because of the lower backgrounds. Analyzing a high radioactivity sample or flushing the detector with P10 gas at too high a flow rate can suspend fine particles and contaminate the detector.
Cost of Equipment: $4K-$5K (manual), $25K-$30K (automatic)
Cost per Measurement: $30 to $50 plus radiochemistry

System: LIQUID SCINTILLATION SPECTROMETER
Lab/Field: Lab (primarily), field (secondarily)
Radiation Detected: **Primary:** Alpha, beta **Secondary:** Gamma
Applicability to Site Surveys: Liquid Scintillation can be a very effective tool for measuring the concentration of radionuclides in soil, water, air filters, and swipes. Liquid scintillation has historically been applied more to beta emitters, particularly the low energy beta emitters ^{3}H and ^{14}C, but it can also apply to other radionuclides. More recently it has been used for measuring radon in air and water. Initial scoping surveys may be done (particularly for loose surface contamination) with surface swipes or air particulate filters. They may be counted directly in liquid scintillation cocktails with no paper dissolution or other sample preparation.
Operation: The liquid scintillation process involves detection of light pulses (usually in the near visible range) by photo-multiplier tubes (or conceptually similar devices). The detected light pulses originate from the re-structuring of previously excited molecular electron structures. The molecular species that first absorb and then re-admit the visible light are called "liquid scintillators" and the solutions in which they reside are called "liquid scintillation cocktails." For gross counting, samples may be placed directly into a LSC vial of cocktail, and counted with no preparation. Inaccuracies result when the sample itself absorbs the radiation before it can reach the LSC cocktail, or when the sample absorbs the light produced by the cocktail. For accurate results, these interferences are minimized. Interferences in liquid scintillation counting due to the inability of the solution to deliver the full energy pulse to the photo-multiplier detector, for a variety of reasons, are called "pulse quenching." Raw samples that cloud or color the LSC cocktail so the resulting scintillations are absorbed will "quench" the sample and result in underestimates of the activity. Such samples are first processed by ashing, radiochemical or solvent extraction, or pulverizing to place the sample in intimate contact with the LSC cocktail. Actions like bleaching the sample may also be necessary to make the cocktail solution transparent to the wavelength of light it emits. The analyst has several reliable computational or experimental procedures to account for "quenching." One is by exposing the sample and pure cocktail to an external radioactive standard and measuring the difference in response.
Specificity/Sensitivity: The method is extremely flexible and accurate when used with proper calibration and compensation for quenching effects. Energy spectra are 10 to 100 times broader than gamma spectrum photopeaks so that quantitative determination of complex multi-energy beta spectra is impossible. Sample preparation can range from none to complex chemical reactions. In some cases, liquid scintillation offers many unique advantages such as no sample preparation before counting in contrast to conventional sample preparation for gas proportional counting. Recent advances in electronic stability and energy pulse shape discrimination has greatly expanded uses. Liquid scintillation counters are ideal instruments for moderate to high energy beta as well as alpha emitters, where the use of pulse shape discrimination has allowed dramatic increases in sensitivity by electronic discrimination against beta and gamma emitters. Additionally, very high energy beta emitters (above 1.5 MeV) may be counted using liquid scintillation equipment without "liquid scintillation cocktails" by use of the Cerenkov light pulse emitted as high energy charged particles move through water or similar substances.
Cost of Equipment: $20,000 to $70,000 based on the specific features and degree of automation
Cost per Measurement: $50 -200 plus cost of chemical separation, if required

H.3 LABORATORY INSTRUMENTS

H.3.3 Gamma Ray Analysis

System: GERMANIUM DETECTOR WITH MULTICHANNEL ANALYZER (MCA)
Lab/Field: Lab
Radiation Detected: **Primary:** Gamma **Secondary:** None
Applicability to Site: This system accurately measures the activity of gamma-emitting radionuclides in a variety of materials like soil, water, air filters, etc. with little preparation. Germanium is especially powerful in dealing with multiple radionuclides and complicated spectra.
Operation: This system consists of a germanium detector connected to a dewar of liquid nitrogen, high voltage power supply, spectroscopy grade amplifier, analog to digital converter, and a multichannel analyzer. P-type germanium detectors typically operate from +2000 to +5000 volts. N-type germanium detectors operate from -2000 to -5000 volts. Germanium is a semiconductor material. When a gamma ray interacts with a germanium crystal, it produces electron-hole pairs. An electric field is applied which causes the electrons to move in the conduction band and the holes to pass the charge from atom to neighboring atom. The charge is collected rapidly and is proportional to the deposited energy. The count rate/energy spectrum is displayed on the MCA screen with the full energy photopeaks providing more useful information than the general smear of Compton scattering events shown in between. The system is energy calibrated using isotopes that emit at least two known gamma ray energies, so the MCA data channels are given an energy equivalence. The MCA's display then becomes a display of intensity versus energy. Efficiency calibration is performed using known concentrations of mixed isotopes. A curve of gamma ray energy versus counting efficiency is generated, and it shows that P-type germanium is most sensitive at 120 keV and trails off to either side. Since the counting efficiency depends on the distance from the sample to the detector, each geometry must be given a separate efficiency calibration curve. From that point the center of each gaussian-shaped peak tells the gamma ray energy that produced it, the combination of peaks identifies each isotope, and the area under selected peaks is a measure of the amount of that isotope in the sample. Samples are placed in containers and tare weighed. Plastic petri dishes sit atop the detector and are useful for small volumes or low energies, while Marinelli beakers fit around the detector and provide exceptional counting efficiency for volume samples. Counting times of 1000 seconds to 1000 minutes are typical. Each peak is identified manually or by gamma spectrometry analysis software. The counts in each peak or energy band, the sample weight, the efficiency calibration curve, and the isotope's decay scheme are factored together to give the sample concentration.
Specificity/Sensitivity: The system accurately identifies and quantifies the concentrations of multiple gamma-emitting radionuclides in samples like soil, water, and air filters with minimum preparation. A P-type detector is good for energies over 50 keV. An N-type or P-type planar (thin crystal) detector with beryllium-end window is good for 5-80 keV energies using a thinner sample placed over the window.
Cost of Equipment: $35,000 to $150,000 based on detector efficiency and sophistication of MCA/computer/software system
Cost per Measurement: $ 100 to $200 (rush requests can double or triple costs)

System: SODIUM IODIDE DETECTOR WITH MULTICHANNEL ANALYZER
Lab/Field: Lab
Radiation Detected: **Primary:** Gamma **Secondary:** None
Applicability to Site Surveys: This system accurately measures the activity of gamma-emitting radionuclides in a variety of materials like soil, water, air filters, etc. with little preparation. Sodium iodide is inherently more efficient for detecting gamma rays but has lower resolution than germanium, particularly if multiple radionuclides and complicated spectra are involved.
Operation: This system consists of a sodium iodide detector, a high voltage power supply, an amplifier, an analog to digital converter, and a multichannel analyzer. The detector is a sodium iodide crystal connected to a photomultiplier tube (PMT). Crystal shapes can vary extensively and typical detector high voltage are 900-1,000 V. Sodium iodide is a scintillation material. A gamma ray interacting with a sodium iodide crystal produces light which is passed to the PMT. This light ejects electrons which the PMT multiplies into a pulse that is proportional to the energy the gamma ray imparted to the crystal. The MCA assesses the pulse size and places a count in the corresponding channel. The count rate and energy spectrum is displayed on the MCA screen with the full energy photopeaks providing more useful information than the general smear of Compton scattering events shown in between. The system is energy calibrated using isotopes that emit at least two gamma ray energies, so the MCA data channels are given an energy equivalence. The MCA's CRT then becomes a display of intensity versus energy. A non-linear energy response and lower resolution make isotopic identification less precise than with a germanium detector. Efficiency calibration is performed using known concentrations of single or mixed isotopes. The single isotope method develops a count rate to activity factor. The mixed isotope method produces a gamma ray energy versus counting efficiency curve that shows that sodium iodide is most sensitive around 100-120 keV and trails off to either side. Counting efficiency is a function of sample to detector distance, so each geometry must have a separate efficiency calibration curve. The center of each peak tells the gamma ray energy that produced it and the combination of peaks identifies each isotope. Although the area under a peak relates to that isotope's activity in the sample, integrating a band of channels often provides better sensitivity. Samples are placed in containers and tare weighed. Plastic petri dishes sit atop the detector and are useful for small volumes or low energies, while Marinelli beakers fit around the detector and provide exceptional counting efficiency for volume samples. Counting times of 60 seconds to 1,000 minutes are typical. The CRT display is scanned and each peak is identified by isotope. The counts in each peak or energy band, the sample weight, the efficiency calibration curve, and the isotope's decay scheme are factored together to give the sample concentration.
Specificity/Sensitivity: This system analyzes gamma-emitting isotopes with minimum preparation, better efficiency, but lower resolution compared to most germanium detectors. Germanium detectors do reach efficiencies of 150% compared with a 3 in. by 3 in. sodium iodide detector, but the cost is around $100,000 each compared with $3,000. Sodium iodide measures energies over 80 keV. The instrument response is energy dependent, the resolution is not superb, and the energy calibration is not totally linear, so care should be taken when identifying or quantifying multiple isotopes. Computer software can help interpret complicated spectra. Sodium iodide is fragile and should be protected from shock and sudden temperature changes.
Cost of Equipment: $6K-$20K
Cost per Measurement: $100-$200 per sample.

EQUIPMENT SUMMARY TABLES

Table H.1 - Radiation Detectors with Applications to Alpha Surveys

Table H.2 - Radiation Detectors with Applications to Beta Surveys

Table H.3 - Radiation Detectors with Applications to Gamma Surveys

Table H.4 - Radiation Detectors with Applications to Radon Surveys

Table H.5 - Systems that Measure Atomic Mass or Emissions

Table H.1 Radiation Detectors with Applications to Alpha Surveys

System	Description	Application	Remarks	Equipment Cost	Measurement Cost
Alpha spectroscopy	A system using silicon diode surface barrier detectors for alpha energy identification and quantification	Accurately identifies and measures the activity of multiple alpha radionuclides in a thin extracted sample of soil, water, or air filters.	Sample requires radiochemical separation or other preparation before counting	$10K-$100K	$250-$400
Alpha scintillation survey meter	<1 mg/cm^2 window, probe face area 50 to 100 cm^2.	Field measurement of presence or absence of alpha contamination on nonporous surfaces, swipes, and air filters, or on irregular surfaces if the degree of surface shielding is known.	Minimum sensitivity is 10 cpm, or 1 cpm with headphones	$1000	$5
Alpha Track Detector	Polycarbonate plastic sheet is placed in contact with a contaminated surface and kept in place	Measures gross alpha surface contamination, soil activity level, or the depth profile of contamination	Alpha radiation produces holes that are enlarged chemically. Density of holes gives a measure of the radioactivity level.		$5-$25
Electret ion chamber	A charged Teflon disk in an open-faced ion chamber	Measures alpha or beta contamination on surfaces and in soils, plus gamma radiation dose or radon concentration	The type of radiation is determined by how the electret is employed, *e.g.*, the unit is kept closed and bagged in plastic to measure gammas	$4,000-$5,000	$8-$25
Long range alpha detector (LRAD)	1m x 1m detector measures ionization inside the box. Attached to tractor for movement. Has location finder and plots graph of contamination.	Measures surface contamination or soil concentration at grid points and plots curves of constant contamination. Intended for large areas.	Alpha detection limit is 20-50 dpm/100 cm^2 or 0.4 Bq/g (10 pCi/g).	$25,000	$80

Table H.1 Radiation Detectors with Applications to Alpha Surveys

System	Description	Application	Remarks	Equipment Cost	Measurement Cost
Gas-flow proportional counter (field)	A detector through which P10 gas flows and which measures alpha and beta radiation. < 1-10 mg/cm^2 window, probe face area 50 to 100 cm^2 for hand held detectors; up to 600 cm^2 if cart mounted	Surface scanning, surface activity measurement, or field evaluation of swipes. Serves as a screen to determine if more nuclide-specific analyses are needed.	Natural radionuclides in samples can interfere with the detection of other contaminants. Requires P10 gas	$2K-$4K	$2-$10/m^2
Gas-flow proportional counter (lab)	Windowless (internal proportional) or window <0.1 mg/cm^2, probe face area 10 to 20 cm^2. May have a second or guard detector to reduce background and MDA.	Laboratory measurement of water, air, and swipe samples	Requires P10 gas. Windowless detectors can be contaminated.	$4K-$30K	$50
Liquid scintillation counter (LSC)	Samples are mixed with LSC cocktail and the radiation emitted causes light pulses with proportional intensity.	Laboratory analysis of alpha or beta emitters, including spectrometry capabilities.	Highly selective for alpha or beta radiation by pulse shape discrimination. Requires LSC cocktail.	$20K-$70K	$50-$200

Table H.2 Radiation Detectors with Applications to Beta Surveys

System	Description	Application	Remarks	Equipment Cost	Measurement Cost
GM survey meter with beta pancake probe	Thin 1.4 mg/cm^2 window detector, probe area 10 to 100 cm^2	Surface scanning of personnel, working areas, equipment, and swipes for beta contamination. Laboratory measurement of swipes when connected to a scaler.	Relatively high detection limit making it of limited value in final status surveys.	$400-$1,500	$5-$10
Gas-flow proportional counter (field)	A detector through which P10 gas flows and which measures alpha and beta radiation. < 1-10 mg/cm^2 window, probe face area 50 to 100 cm^2	Surface scanning, surface activity measurement, or field evaluation of swipes. Serves as a screen to determine if more nuclide-specific analyses are needed.	Natural radionuclides in samples can interfere with the detection of other contaminants. Requires P10 gas, but can be disconnected for hours.	$2K-$4K	$2-$10/m^2
Gas-flow proportional counter (lab)	Windowless (internal proportional) or window <0.1 mg/cm^2, probe face area 10 to 20 cm^2. May have a second or guard detector to reduce background and MDA.	Laboratory measurement of water, air, and swipe samples	Requires P10 gas. Windowless detectors can be contaminated.	$4K-$30K	$50
Liquid scintillation counter (LSC)	Samples are mixed with LSC cocktail and the radiation emitted causes light pulses with proportional intensity.	Laboratory analysis of alpha and beta emitters, including spectrometry capabilities.	Highly selective for alpha and beta radiation by pulse shape discrimination. Requires LSC cocktail.	$20K-$70K	$100-$200

Table H.3 Radiation Detectors with Applications to Gamma and X-Ray Surveys

System	Description	Application	Remarks	Cost of Equipment	Cost per Measurement
GM survey meter with gamma probe	Thick-walled 30 mg/cm^2 detector	Measure radiation levels above 0.1 mR/hr.	Its non-linear energy response can be corrected by using an energy compensated probe.	$400-$1,000	$5
Pressurized ion chamber (PIC)	A highly accurate ionization chamber that is rugged and stable.	Excellent for measuring gamma exposure rate during site remediation.	Is used in conjunction with radionuclide identification equipment.	$15K - $50K	$50 - $500
Electret ion chamber	Electrostatically charged disk inside an ion chamber	Gamma exposure rate	N/A, rented	included in rental price	$8 - $25
Hand-held ion chamber survey meter	Ion chamber for measuring higher radiation levels than typical background.	Measures true gamma exposure rate.	Not very useful for site surveys because of high detection limit above background levels.	$800-$1,200	$5
Hand-held pressurized ion chamber survey meter	Ion chamber for measuring higher radiation levels than typical background.	Measures true gamma exposure rate with more sensitivity than the unpressurized ion chamber.	Not very useful for site surveys because of high detection limit above background levels.	$1,000-$1,500	$5
Sodium Iodide survey meter	Detectors sizes up to 8"x8". Used in micro R-meter in smaller sizes.	Measures low levels of environmental radiation.	Its energy response is not linear, so it should be calibrated for the energy field it will measure or have calibration factors developed by comparison with a PIC for a specific site.	$2K	$5
FIDLER (Field Instrument for Detection of Low Energy Radiation)	Thin crystals of NaI or CsI.	Scanning of gamma/X radiation from plutonium and americium.		$6K-$7K	$10-$20

Table H.3 Radiation Detectors with Applications to Gamma and X-Ray Surveys

System	Description	Application	Remarks	Cost of Equipment	Cost per Measurement
Sodium iodide detector with multichannel analyzer (MCA)	Sodium iodide crystal with a large range of sizes and shapes, connected to a photomultiplier tube and MCA.	Laboratory gamma spectroscopy to determine the identity and concentration of gamma emitting radionuclides in a sample.	Sensitive for surface soil or groundwater contamination. Analysis programs have difficulty if sample contains more than a few isotopes.	$6K-$20K	$100 to $200
Germanium detector with multichannel analyzer (MCA)	Intrinsic germanium semiconductor in p- or n-type configuration and without a beryllium window.	Laboratory gamma spectroscopy to determine the identity and concentration of gamma emitting radionuclides in a sample.	Very sensitive for surface soil or groundwater contamination. Is especially powerful when more than one radionuclide is present in a sample.	$35K-$150K	$100 to $200
Portable Germanium Multichannel Analyzer (MCA) System	A portable version of a laboratory based germanium detector and multichannel analyzer.	Excellent during characterization through final status survey to identify and quantify the concentration of gamma ray emitting radionuclides and in situ concentrations of soil and other media	Requires a supply of liquid nitrogen or a mechanical cooling system, as well as highly trained operators.	$40K	$100
Field x-ray fluorescence spectrometer	Uses silicon or germanium semiconductor	Determining fractional abundance of low percentage metal atoms.		$15K-$75K	$200
Thermoluminescence dosimeters (TLDs)	Crystals that are sensitive to gamma radiation	Measure cumulative radiation dose over a period of days to months.	Requires special calibration to achieve high accuracy and reproducibility of results.	$5K-$50K for reader + $25-$40 per TLD	$25-$125

Table H.4 Radiation Detectors with Applications to Radon Surveys

System	Description	Application	Remarks	Equipment Cost	Measurement Cost
Large area activated charcoal collector	A canister containing activated charcoal is twisted into the surface and left for 24 hours.	Short term radon flux measurements	The LLD is 0.007 Bq $m^{-2}s^{-1}$ (0.2 pCi $m^{-2}s^{-1}$).	N/A, rented	$20-$50 including canister
Continuous radon monitor	Air pump and scintillation cell or ionization chamber	Track the real time concentration of radon	Takes 1 to 4 hours for system to equilibrate before starting. The LLD is 0.004-0.04 Bq/L (0.1-1.0 pCi/L).	$1K-$5K	$80
Activated charcoal adsorption	Activated charcoal is opened to the ambient air, then gamma counted on a gamma scintillator or in a liquid scintillation counter.	Measure radon concentration in indoor air	Detector is deployed for 2 to 7 days. The LLD is 0.007-0.04 Bq/L (0.2 to 1.0 pCi/L).	$10K-$30K	$5-$30 including canister if outsourced.
Electret ion chamber	This is a charged plastic vessel that can be opened for air to pass into.	Measure short-term or long-term radon concentration in indoor air.	Must correct reading for gamma background concentration. Electret is sensitive to extremes of temperature and humidity. LLD is 0.007-0.02 Bq/L (0.2-0.5 pCi/L).	N/A, rented	$8-$25 for rental
Alpha track detection	A small piece of special plastic or film inside a small container. Damage tracks from alpha particles are chemically etched and tracks counted.	Measure indoor or outdoor radon concentration in air.	LLD is 0.04 Bq $L^{-1}d^{-1}$ (1 pCi $L^{-1}d^{-1}$).		$5-$25

Table H.5 Systems that Measure Atomic Mass or Emissions

System	Description	Application	Remarks	Cost of Equipment	Cost per Measurement
LA-ICP-AES (Laser Ablation Inductively Coupled Plasma Atomic Emissions Spectrometer)	Vaporizes and ionizes the surface material, and measures emissions from the resulting atoms.	Live time analysis of radioactive U and Th contamination in the field.	Requires expensive equipment and skilled operators. LLD is 0.004 Bq/g (0.1 pCi/g) for ^{232}Th and 0.01 Bq/g (0.3 pCi/g) for ^{238}U.	>$1,000,000	$4,000
LA-ICP-MS (Laser Ablation Inductively Coupled Plasma Mass Spectrometer)	Vaporizes and ionizes the surface material, then measures the mass of the resulting atoms.	Live time analysis of radioactive U and Th contamination in the field.	Requires expensive equipment and skilled operators. More sensitive than LA-ICP-AES. LLD is 0.6 Bq/g (15 pCi/g) for ^{230}Th.	>$1,000,000	>$4,000
Chemical speciation laser ablation/mass spectrometer	A laser changes the sample into an aerosol that it analyzed with a mass spectrometer.	Analyze organic and inorganic species with high sensitivity and specificity.	Volatilized samples can be carried hundreds of feet to the analysis area.	>$1,000,000	>$4,000